Volume 32 NOVEMBER, 1948 NUMBER 11

BULLETIN
of the
American Association *of* Petroleum Geologists

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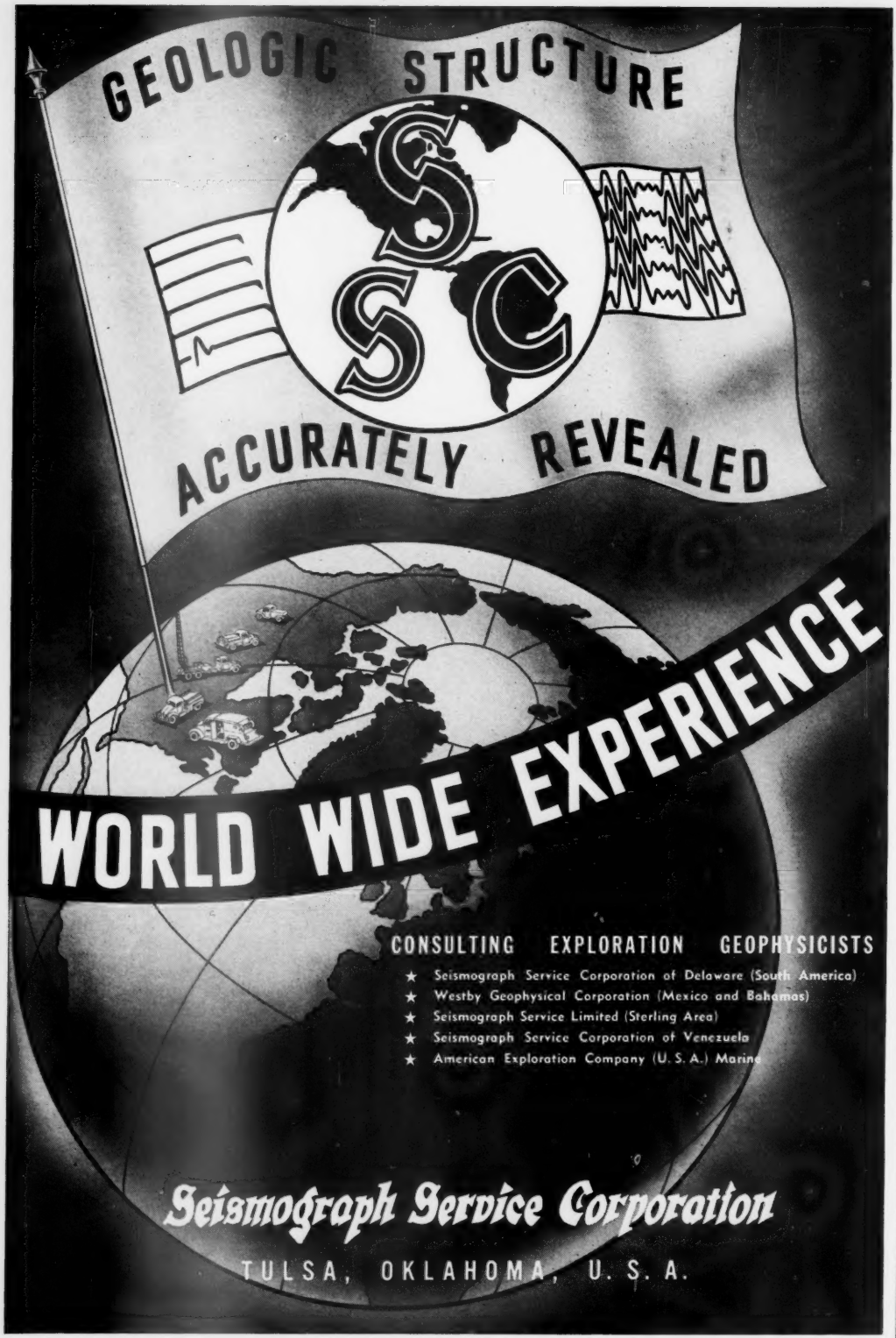
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THE BULLETIN is published by the Association on the 15th of each month.

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BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

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Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

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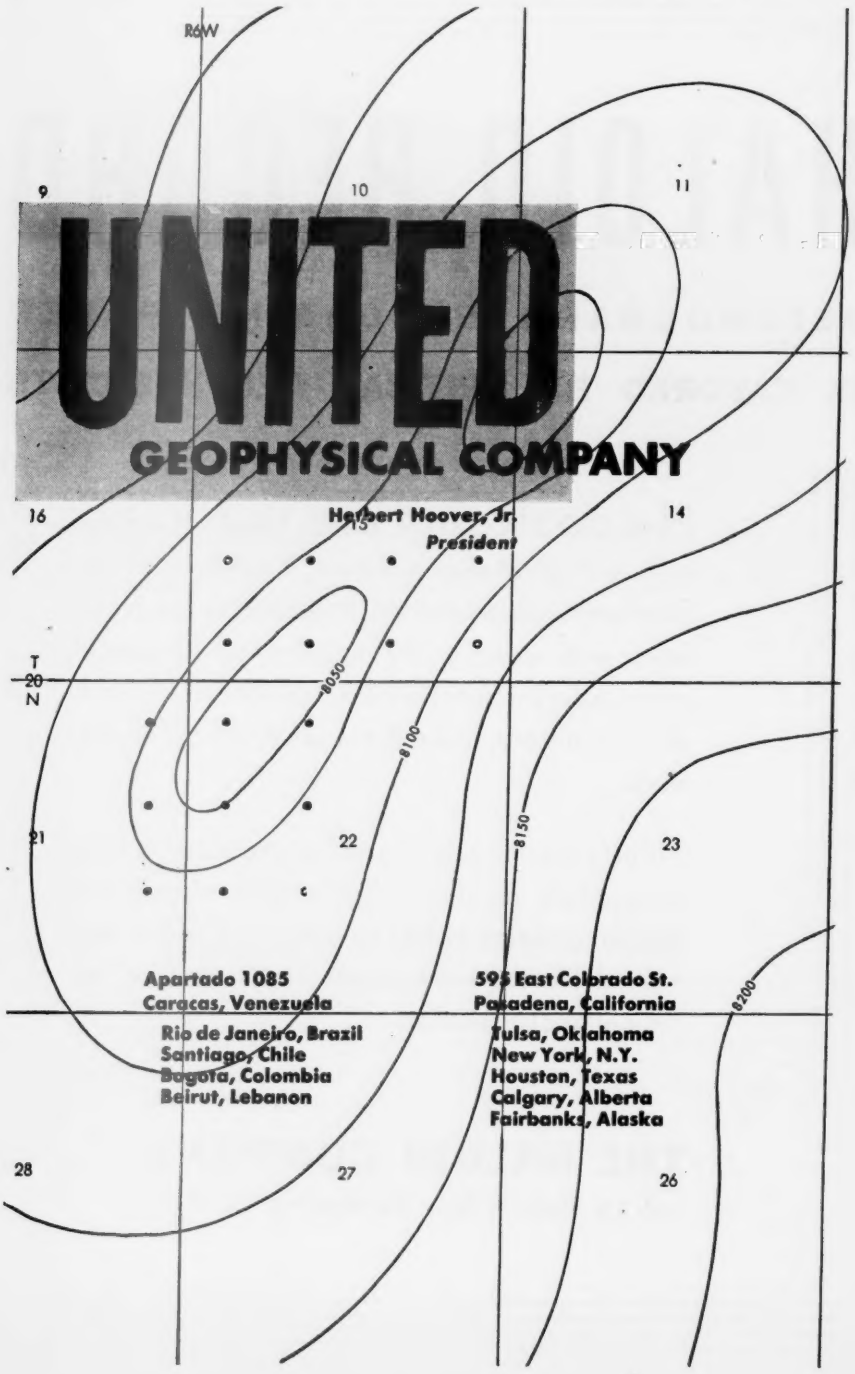
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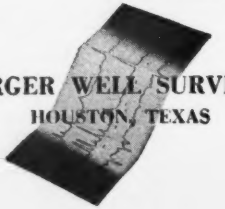

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Volume 32 Number 11

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

NOVEMBER, 1948

CLASSIFICATION OF PENNSYLVANIAN ROCKS IN IOWA, KANSAS, MISSOURI, NEBRASKA, AND NORTHERN OKLAHOMA[1]

RAYMOND C. MOORE[2]
Lawrence, Kansas

An agreement of the State geological surveys of Iowa, Kansas, Missouri, Nebraska, and Oklahoma on all major and many minor features of Pennsylvanian classification affecting territory northeastward from northern Oklahoma is an important step toward simplification of nomenclature and elimination of confusion.

The stratigraphic succession of Pennsylvanian rocks in the northern Mid-Continent area is well suited to serve as an important standard of reference in studying Pennsylvanian sections and geological history in other areas. The classification of these rocks in the several states, developed mainly during the last 50 years, has had many features in common but also has exhibited noteworthy discrepancies. Establishment of a classification that ignores State boundaries has general interest to geologists.

The State surveys agree in recognizing Pennsylvanian rocks as a geological system and in defining major time-rock subdivisions within the system, which in upward order are called Desmoinesian, Missourian, and Virgilian. Older units, such as Springeran, Morrowan, and Atokan, are not excluded from recognition where they may be differentiated. Groups are defined as follows, in upward order: Cherokee, Marmaton, Pleasanton, Kansas City, Lansing, Pedee, Douglas, Shawnee, Wabaunsee, except that in northern Oklahoma and part of southern Kansas, rocks of Missourian age are recognized as belonging to the Skiatook and Ochelata groups. Bourbon, previously used in Kansas and Nebraska, is abandoned in favor of Pleasanton. The Kansas City group is defined as extending from the base of the Hertha limestone to the base of the Plattsburg limestone; it contains three subgroups called Bronson, Linn (new), and Zarah (new). The Wabaunsee group, also, may be divided into subgroups named Sacfox, Nemaha, and Richardson.

Not considered by the inter-state conference is use of lithologic classificatory terms for units

[1] Manuscript received, June 19, 1948.

[2] Director, Kansas Geological Survey. It is appropriate to express appreciation of the very cordial attitude of all the concerned State geologists and associated workers of the geological surveys who are engaged with problems of Pennsylvanian classification and nomenclature. There is a common desire to avoid discrepant usage of terms and to adjust divergent viewpoints so far as possible. Where the rocks themselves differ and judgment concerning classification can not be reconciled, nomenclature can not be uniform, but there is intent to avoid use of the same term with different meanings.

The manuscript of this paper has been read by Edward L. Clark, Frank C. Greene, and Walter V. Searight, of the Missouri Geological Survey; H. Garland Hershey and Lewis M. Cline, of the Iowa Geological Survey; George E. Condra and Eugene C. Reed, of the Nebraska Geological Survey; Robert H. Dott and Malcolm C. Oakes, of the Oklahoma Geological Survey; and John C. Frye and J. Mark Jewett, of the Kansas Geological Survey. Sincere thanks are expressed for assistance furnished by these geologists.

classed as formations which are made up of two or more kinds of rock. Some surveys are disposed to designate such units by the term "formation," rather than to call them "limestone," if their dominant constituent is limestone, or "shale," if they are mainly shale but contain other kinds of sedimentary rock also.

INTRODUCTION

The achievement of substantially complete agreement on stratigraphic classification and nomenclature of Pennsylvanian rocks by five State geological surveys in the northern Mid-Continent region, as recorded in this paper, seems worthy of more than passing notice. In the first place, such agreement reflects the very great advancement in detailed knowledge of this system which has been developed during decades of investigations in Iowa, Kansas, Missouri, Nebraska, and Oklahoma, for if the nature and distribution of Pennsylvanian strata were less well studied, divergence in nomenclature inevitably would persist. Secondly, the agreement emphasizes the fact of general similarity in facies which characterizes Pennsylvanian deposits from north-central Iowa to northeastern Oklahoma, for if identifiable rock layers were less persistent, essential uniformity in designating stratigraphic units throughout this region would be unattainable. Thirdly, effort to standardize classification and nomenclature of the northern Mid-Continent Pennsylvanian reflects both a large degree of common judgment among competent students who have worked in the area and a united aim on the part of these investigators and of State geological survey officials to eliminate confusing differences in stratigraphic nomenclature. Inasmuch as rock units do not terminate at State boundaries, obviously it is advantageous to define and designate them identically on each side of these boundaries.

USE OF STRATIGRAPHIC NAMES

When individual components of a rock succession like that in the Pennsylvanian area of the northern Mid-Continent[3] are named diversely in different states, one may logically conclude that the designated lithologic divisions are dissimilar, or that stratigraphic equivalence of differently named units has not been established. The differences in nomenclature may arise either from differences in the rocks or from uncertainties of correlation. For example, field work by Bain (1898) in south-central Iowa, a half-century ago, led to definition of limestone units called DeKalb and Westerville. A limestone in the section at Kansas City which was called Drum (Hinds and Greene, 1915), was traced by G. E. Condra, F. C. Greene, and R. C. Moore in 1932 to the type area of the DeKalb and Westerville limestones, where it was found to be the same as Westerville; accordingly, this limestone at Kansas City and elsewhere is now called Westerville. The DeKalb was found to be a synonym of Winterset limestone (Tilton, 1897) and has been dropped, whereas Drum is now known to apply properly to a

[3] For purposes of the discussion in this paper, "northern Mid-Continent" refers to areas of Pennsylvanian rocks (surface and subsurface) in Iowa, Kansas, Missouri, Nebraska, and Oklahoma as far south as the latitude of Tulsa.

limestone that overlies the Westerville. The retention of different names in different areas for an actually identical unit is not a source of confusion, but when proof of identity is established, continued use of synonymous terms is objectionable because nomenclature is needlessly burdened.

Use of the same name for entirely different stratigraphic units is quite another matter. Clearly this is an intolerable source of trouble, particularly after it becomes well known that the identically named divisions lack equivalence. For example, the Tarkio limestone (Calvin, 1901), as defined by type outcrops in southwestern Iowa, is known now (Moore, 1936, p. 229; Condra and Reed, 1943, p. 45) to designate a limestone unit occurring 30–65 feet below the distinctive, widely recognized limestone to which the name Tarkio has come to be applied in the northern Mid-Continent. If geologists of Iowa insisted on calling the lower limestone Tarkio because it is the rock designated by Calvin's original definition, while geologists of Nebraska and Kansas persisted in designating the higher, entirely different limestone as Tarkio, the conflicting usage would be an indefensible source of confusion. Similarly, discrepant definition of Iola limestone in Kansas and Missouri during many years has affected inter-state classification disturbingly. By tacit agreement, definition of Tarkio limestone has come to apply to a unit belonging stratigraphically well above Calvin's type and this has validity by reason of universal acceptance. Homonyms, such as Tarkio and Iola, represent errors. As soon as the error is recognized, conflicting application of the name should be suppressed, normally by abandoning the incorrect usage.

Some stratigraphic names have divergent meanings because of attempted revision of their application. If revision is immediately and universally accepted, confusion is reduced to a minimum, because definition of the unit as understood before the date of revision is disregarded by every one. If the revision is not generally accepted, there is confusingly divided usage. In any case, the divergent definitions of terms are purposeful. An example is furnished by the Kansas City group, which in Missouri and Iowa has been used consistently for many years to include Hertha-to-Argentine beds, whereas in Kansas and Nebraska since 1932 the Kansas City group has been defined with entirely different lower and upper boundaries. Such divergence in usage is highly objectionable, because clarity of understanding on the part of a reader requires that he know what definition of the term is intended. Homonyms that result from emendation of stratigraphic names are vexatious in proportion to the extent to which revision is accepted by some geologists but ignored by others.

Workers engaged in stratigraphic research or having occasion to use stratigraphic terms are well advised generally to avoid emendation of such terms. If revised definition of a unit or units seems to be required, stability of stratigraphic terminology is disturbed either by revising the meaning of old names or by introducing new ones, but emendation commonly creates greater confusion. A new name eliminates ambiguity but sacrifices the capital represented by maintaining an old familiar name.

SCOPE OF AGREEMENTS ON STRATIGRAPHIC NOMENCLATURE

Stratigraphical geology is burdened by synonymous stratigraphic names like a ship impeded by barnacles. There is danger of sinking the stratigraphical ship if it becomes burdened by a multitude of homonyms. Agreement on questions of nomenclature by organizations such as State and Federal geological surveys or by representative groups of geologists belonging to associations and societies undoubtedly will contribute much to betterment of stratigraphical literature. Joint consideration of divergent Pennsylvanian nomenclature, which has been undertaken by the geological surveys of northern Mid-Continent states, has yielded results that may be hoped for in other areas and circumstances.

The agreements by the State surveys include recognition of Pennsylvanian rocks as a geologic system and acceptance of major divisions of the Pennsylvanian called Desmoinesian, Missourian, and Virgilian. Groups are defined both as to name and stratigraphic span. Uniform nomenclature of many lesser stratigraphic units (formations and members) having inter-state areal distribution also is adopted. The agreements provide essential uniformity in treatment of the Pennsylvanian rocks throughout the region but do not "freeze" classification, (1) because features of local stratigraphy within any of the states, which are judged not to affect out-of-state areas, are a concern of the State itself and may be named without consulting neighboring State surveys, and (2) because changes in nomenclature affecting any two or more states may be introduced on the basis of approval by an inter-state conference, with provision, however, that if such conference fails to agree, no change of nomenclature will be made by any State survey involving revision of an old stratigraphic name which some survey wishes to retain.

DEVELOPMENT OF CLASSIFICATION

The presence of coal-bearing strata, now classed as Pennsylvanian, was recorded in the Mid-Continent region 125 years ago (Long, 1823), but earliest explorations included no effort to classify the succession of these rocks. A beginning of systematic stratigraphical work was made when Meek and Hayden (1859) studied the Pennsylvanian section of the Kansas River Valley, and B. F. Mudge (1866), first State geologist of Kansas, described Carboniferous strata exposed in eastern Kansas. Swallow and Hawn (1865) and Swallow (1866) constructed a composite section of Pennsylvanian rocks observed in eastern Kansas, in which geographic names such as Fort Scott, Stanton, and Plattsburg were first applied to stratigraphic divisions. In Missouri, excellent work on the Pennsylvanian section exposed along the Missouri River was done by G. C. Broadhead (1866) who constructed a composite section in which stratigraphic units (numbered 1–284) were so described that most of them are readily identifiable by later geologists. Subsequently, Broadhead (1895) revised and renumbered this section (Nos. 1–224), but very few divisions were given geographic names.

During the 1860's the Geological Survey of Iowa made a general study of the so-called Coal Measures which are exposed in the central and southwestern part of that state (White, 1870). Meek (1872) published descriptions of Pennsylvanian strata and fossils of eastern Nebraska.

No work of importance seems to have been done during the following two decades, but beginning in 1890 there was much activity. Haworth and associates of the reorganized Kansas Geological Survey made several traverses across the Pennsylvanian outcrops along selected lines and introduced many new stratigraphic names. Correlation of these sections showed that some strata were differently named in the various sections. A classification was developed (Haworth, 1894, 1895; Haworth and Kirk, 1894) in which all of the Pennsylvanian deposits were assigned to named groups and formations. In Iowa, surveys were made of several counties in which Pennsylvanian rocks are exposed and in the course of this work various stratigraphic units were named. Some work was done on coal resources of Missouri and knowledge of the rocks associated with the coal beds was extended. First efforts to classify Pennsylvanian rocks in northeastern Oklahoma are recorded in the work of Drake (1897).

The most important publications dealing with Pennsylvanian rocks in the northern Mid-Continent region in the period from 1900 to 1909 were a report of the Kansas Geological Survey (Haworth and Bennett, 1908) and a bulletin (Adams, Girty, and White, 1903) issued by the United States Geological Survey on Upper Carboniferous rocks of Kansas. These contain a summary of the stratigraphy of the Pennsylvanian formations as then known, and observations on paleontological characters of successive divisions. The Haworth paper was accompanied by the first comprehensive survey of Pennsylvanian invertebrate faunas (Beede and Rogers, 1908).

The years 1910–1919 witnessed activities in Pennsylvanian stratigraphic investigations throughout most of the Mid-Continent area. Chiefly important were reports by Hinds (1912) on coal and by Hinds and Greene (1915) on stratigraphy of Pennsylvanian deposits in Missouri. The latter paper was accompanied by paleontological discussions on invertebrates by Girty (1915) and on plants by White (1915). In Oklahoma, the first effort to describe and classify Pennsylvanian strata in the northeastern part of the state (Ohern, 1910) and a series of oil and gas surveys by Federal geologists laid the foundation of classification and nomenclature of these rocks in the northern part of the state. In Kansas, summaries of Pennsylvanian stratigraphy were published (Moore and Haynes, 1917, pp. 78–107; Moore, 1920) which include some modifications of Haworth's classification and incorporate features derived from the work of Hinds and Greene; no new studies of importance were undertaken, however. The first modern work on Pennsylvanian rocks in Nebraska was recorded in a paper by Condra and Bengston (1915).

In the 1920's, work deserving special mention is the first comprehensive report on Pennsylvanian rocks of Nebraska (Condra, 1927), in which numerous

subdivisions of previously defined formations were named. Although serious errors in interpretation of some units were made, especially in correlating the Platte Valley section, Condra's studies indicated the great persistence of many minor divisions of the rock succession and by introduction of formal nomenclature for them he laid groundwork for more detailed and precise stratigraphy of Mid-Continent Pennsylvanian deposits.

Partly from the impetus of Condra's work and partly from other activation, especially interest in exploring evidence of cyclic sedimentation, study of Pennsylvanian stratigraphy was accelerated in the Mid-Continent area in the 1930's. Work was done in all of the states. In Kansas, stratigraphic sections and maps were gathered from oil companies and other sources for use in compiling a state geologic map. Moore, Newell, Jewett, Schoewe, Elias, and other survey members did field work in every county having Pennsylvanian outcrops. Classification of rocks belonging to the system was revised in several ways, by recognizing major time-rock divisions bounded by disconformities, by changing the assigned limits of some main lithologic units (groups) and by applying results of cyclic sedimentation studies to definition of many formation and member units (Moore, 1932, 1936; Newell, 1935; Jewett, 1933; Jewett and Newell, 1935). The half-million scale geologic map of Kansas, embodying features of the new classification of Pennsylvanian rocks, was published in 1937 (Moore and Landes). In Nebraska and Iowa, Condra and associates (Condra, 1930, 1933, 1935; Condra and Upp, 1933, 1933a; Condra and Reed, 1937; Condra and Scherer, 1939) published several papers giving information and new conclusions as to identification and stratigraphic classification of rock units, mostly of Missourian and Virgilian age. In 1932, D. G. Stookey and M. L. Thompson began studies of the Desmoinesian rocks of Iowa, working under direction of A. C. Tester, but results are unpublished except for a paper by Thompson (1934) on fusulines from some of the lower beds. Detailed work on upper Desmoinesian and lower Missourian strata of Iowa was carried on by L. M. Cline during the years 1935–1941. Some of the stratigraphic results, including correlation of Iowa and Missouri units, have been reported by Cline (1941). McQueen and Greene (1938) published a comprehensive report on oil and gas exploration in northwestern Missouri, with which a chart showing lithologic features and classification of the Pennsylvanian column of that state was offered. Several papers on stratigraphy of Pennsylvanian rocks in Oklahoma were published, and, through collaboration of oil company geologists, numerous subsurface cross sections, showing the nature and correlation of Pennsylvanian rock units in Oklahoma and Kansas, were prepared. Although these sections were not published, they were reproduced in sufficiently large number for private distribution to investigators and they have supplemented surface stratigraphic studies in important manner.

The years from 1940 to the present have been somewhat less productive of advances in knowledge of Mid-Continent Pennsylvanian rocks than some previous equal periods. Conditions imposed by World War II have been responsible for

this to a large extent, both by separation from the region of geologists who had been working on these problems and by diverting chief attention of geologists who remained in the area to other work. In this period two reports of continent-wide scope (Moore *et al.*, 1944; Cheney *et al.*, 1945) have been issued that treat classification and correlation of Pennsylvanian rocks in the Mid-Continent states. In less detail, the Pennsylvanian deposits were reviewed also in a survey of Mid-Continent stratigraphy (Dott, 1941). An important paper by Cline (1941) gives results of his studies on Pennsylvanian rocks in Iowa, with indication of equivalent rock units in Missouri. A comprehensive summary of Pennsylvanian classification in Nebraska was published in 1943 by Condra and Reed and a similar one for Kansas, in 1944, by Moore, Frye, and Jewett. Studies of upper Desmoinesian (Jewett, 1941, 1945) and lower Virgilian (Bowsher and Jewett, 1943) rocks in Kansas contain important contributions to knowledge. Work in northeastern Oklahoma by Oakes (1940) makes additions to knowledge of Pennsylvanian rocks in this area.

Comparison of classification of Pennsylvanian rocks in the northern Mid-Continent states, particularly as represented by comprehensive papers published between 1930 and 1945, reveals many divergences, despite growing recognition of the identity of most rock units on opposite sides of state boundaries. Use of a different name for the same rock unit in two adjoining states (as Dennis limestone in Kansas, Hogshooter limestone in Oklahoma) represents lack of uniformity but is not a source of confusion. Use of the same name for different rocks on opposite sides of a state boundary (as Iola limestone and Kansas City group in Kansas and Missouri) is obviously objectionable.

INTER-STATE CONFERENCE ON PENNSYLVANIAN CLASSIFICATION

Plans for a meeting of State geologists representing Iowa, Kansas, Missouri, Nebraska, and Oklahoma, for the purpose of analyzing inter-state divergences in classification and nomenclature of Pennsylvanian deposits in the northern Mid-Continent area, were made in 1946, but it proved infeasible to hold such a meeting until May 5–6, 1947. On invitation of R. C. Moore, the conference was held in offices of the Kansas Geological Survey at Lawrence. Those present were: for Iowa, L. M. Cline; for Kansas, R. C. Moore, J. C. Frye, and J. M. Jewett; for Missouri, E. L. Clark, F. C. Greene, and W. V. Searight; for Nebraska, G. E. Condra and E. C. Reed. Wallace Lee, of the United States Geological Survey, attended the sessions as observer. R. H. Dott, State geologist of Oklahoma, was unable to be present, but on the basis of oral discussion with Moore on May 8 and examination of the report given in this paper, has expressed concurrence, with qualifications recorded in appropriate parts of the paper.

Discussions at Lawrence extended from 8 A.M. to 6 P.M. on May 5. The following day, May 6, was devoted to study in the field for the purpose of checking equivalence of Paola-to-Raytown beds in the Kansas City area to the Iola limestone at its type locality and for observations of overlying strata upward to the

Plattsburg limestone in the area between Kansas City and Iola. Geologists participating in this field conference were Clark, Greene, Jewett, Moore, and Searight.

The discussions reached essential accord on all points, subject to acceptance on the part of Missouri of correlations between Kansas City and Iola that had been made by Kansas. The field work sufficed to remove doubts of the Missouri geologists on correctness of identifying the Paola-to-Raytown strata of the Kansas City area with type Iola limestone, and this permitted agreement of the Missouri Geological Survey to changes in stratigraphic nomenclature that depend on this identification.

OUTLINE OF INTER-STATE PENNSYLVANIAN CLASSIFICATION

The classification and nomenclature of Pennsylvanian units developed by the conference is given in accompanying charts (Figs. 1–6) which also show usage of Pennsylvanian stratigraphic names in the several states shortly before the date of the conference. These make clear the nature of changes. The column for Oklahoma in the charts refers only to the northern border region of that state, because southward change of facies makes it necessary to introduce many terms that are inapplicable in the north. Supplemental notes on major and minor stratigraphic divisions are recorded in following paragraphs.

TIME-ROCK UNITS—SYSTEM, SERIES, STAGE

General considerations.—Clear distinction is recognized between divisions of Pennsylvanian rocks in the Mid-Continent region that are based on relation to boundaries having significance as markers of geologic time and those that are defined primarily by lithologic characters. The boundaries of time-rock units are obscure but geographically extensive disconformities that separate successions of strata having different paleontological attributes. Greatest change in the components of fossil faunas and floras closely coincides with the horizons of these disconformities, which are inferred, therefore, to denote relatively prolonged interruptions in sedimentation. Erosion of previously accumulated deposits, which is indicated at many places as accompaniment of non-deposition, ranges from barely perceptible to a very considerable quantity. The deposits occurring next above the disconformable surfaces are prevailingly clastic. They include much sandstone and there are local or widespread conglomerate beds. The clastic sediments increase in prominence outward from basin areas, as in the Forest City and Salina basins, and especially toward source areas of sediments. All known features of surface and subsurface stratigraphy of Pennsylvanian rocks in the northern Mid-Continent area point to, or are in accord with, the recognition of at least four major time-rock units, and the Pennsylvanian column in parts of the region may be divisible into five or six such time-rock elements.

The rank to which the units under discussion should be assigned hinges on decisions concerning collateral features of classification. If Pennsylvanian rocks

are designated as a system or subsystem, divisions such as Desmoinesian and Missourian may be treated appropriately as series; or if an Upper Pennsylvanian Series is judged desirable, it may be composed of the Missourian Stage and Virgilian Stage. The conference of State geologists made no commitment on the matter of rank assignable to time-rock divisions of the Pennsylvanian. In the following paragraphs the time-rock units discussed are treated as series.

The representatives of the State geological surveys meeting at Lawrence acquiesced in judgment that the recommendations submitted by Moore (1947) to the American Commission on Stratigraphic Nomenclature, calling for uniform use of adjectival names for time-rock and time units and capitalization of the initial letter of these classificatory terms when used with a named unit, are desirable for general adoption. These matters were not brought forward, however, as items of formal inter-state agreement.

Springeran Series.—Pre-Morrowan Pennsylvanian rocks are not known definitely to occur in northern Oklahoma or states farther north, although some geologists think that such deposits, classed as Springeran (from outcrops in the Ardmore basin), are present in northwestern Arkansas. Equivalent old Pennsylvanian strata may be found somewhere in the subsurface of Kansas or near-by areas but they are not believed to crop out.

Morrowan Series.—Deposits of Morrowan age are exposed in northeastern Oklahoma and are recognized in the subsurface of western Kansas (Thompson, 1944; Maher, 1947). In terms of fusuline zonation, the Morrowan deposits are defined as belonging in the zone of *Millerella*. Morrowan rocks have not been discovered in other parts of the northern Mid-Continent region and this division of the Pennsylvanian is recognized in agreed classification as applicable to Kansas and Oklahoma. Probably throughout the northern Mid-Continent area, including Pennsylvanian deposits north of the latitude of Tulsa, the lower boundary of the Morrowan Series, where rocks of this age are present, coincides with the major unconformity that separates Pennsylvanian from older systems. The upper boundary is a well marked disconformity in most places, but in parts of the subsurface there is indication that Morrowan strata are limited above by a disconformity or non-conformity. The superjacent rocks seem definitely assignable to the Desmoinesian Series in parts of the region, but in other parts post-Morrowan-pre-Desmoinesian beds may be differentiated.

Atokan Series.—This name has been introduced in classifying buried Pennsylvanian deposits of western Kansas and eastern Colorado (Maher, 1947), but was not proposed for discussion in developing agreed classification among the northern Mid-Continent states. The Atokan comprises the zone of *Fusulinella*. If deposits younger than Morrowan and older than Desmoinesian are differentiated in Oklahoma, Nebraska, Missouri, and Iowa, their nomenclature remains to be considered. L. M. Cline reports that there is a prominent disconformity below the horizon of the Munterville limestone, not far above the base of the Iowa Pennsylvanian, and beds below this disconformity, which contain

Fusulinella (Moore *et al.*, 1944, p. 691), may be pre-Desmoinesian, but they are insufficiently studied. Geologists of the Iowa Survey are not ready to propose any change in definition of the Desmoinesian rocks, the base of which lies on Mississippian strata in the type area.

Desmoinesian Series.—The type locality of this time-rock division, which is designated paleontologically as the zone of *Fusulina*, is in Iowa. In some parts of northern Mid-Continent states, Desmoinesian deposits are separable from underlying pre-Desmoinesian Pennsylvanian rocks, but in large areas, especially in the subsurface of northern Oklahoma and Kansas along the Nemaha Ridge and bordering the Central Kansas uplift, Desmoinesian beds rest on pre-Pennsylvanian formations with angular unconformity. The upper boundary of the Desmoinesian Series is defined by a disconformity which is very inconspicuous in most places but, on the basis of paleontological changes, is judged to be a division line of first-rank intra-systemic magnitude. Beds next above the break belong to the Missourian Series.

The inter-state conference has recognized Desmoinesian as having the limits here indicated (Fig. 1). This merely confirms previous common definition of the boundaries but it involves substituting Desmoinesian Series for Des Moines series in style of writing. In many sections all pre-Missourian rocks of Pennsylvanian age are classed as Desmoinesian.

Missourian Series.—For many years all Pennsylvanian strata in the northern Mid-Continent area above the so-called Des Moines group, or Lower Coal Measures, were known as the Missouri group, or Upper Coal Measures. The boundary between these "groups" was formerly drawn at the base of the Hertha limestone, or base of the Kansas City formation of Missouri Geological Survey usage. Moore (1932) relocated this boundary to coincide with the regional disconformity occurring 5–100 feet below the Hertha and he classed the redefined Des Moines as a series; the former Missouri group, with addition of strata below and removal of beds above, was designated as the Missouri series. Studies shortly prior to 1932 had brought to attention the existence of a widespread disconformity in the middle part of the old "Missouri group" and this seemed to rank in importance with other main time-rock boundaries in the Pennsylvanian System. It is less emphasized paleontologically than the boundary marking the top of the Desmoinesian strata, however. The deposits occurring between the post-Desmoinesian disconformity and that in the mid-part of the Upper Pennsylvanian, just mentioned, are classed as belonging to the Missourian Series. This time-rock division comprises the lower part of the zone of *Triticites*.

The Missourian Series, with the stated boundaries (Fig. 1), has been accepted by all northern Mid-Continent State geological surveys. The designated Missouri series is changed to Missourian Series; also, the Missouri Geological Survey restricts the stratigraphic span of this term so that future official usage in that state will conform to the definition adopted in neighboring areas.

Virgilian Series.—Uppermost Pennsylvanian rocks, lying between the post-

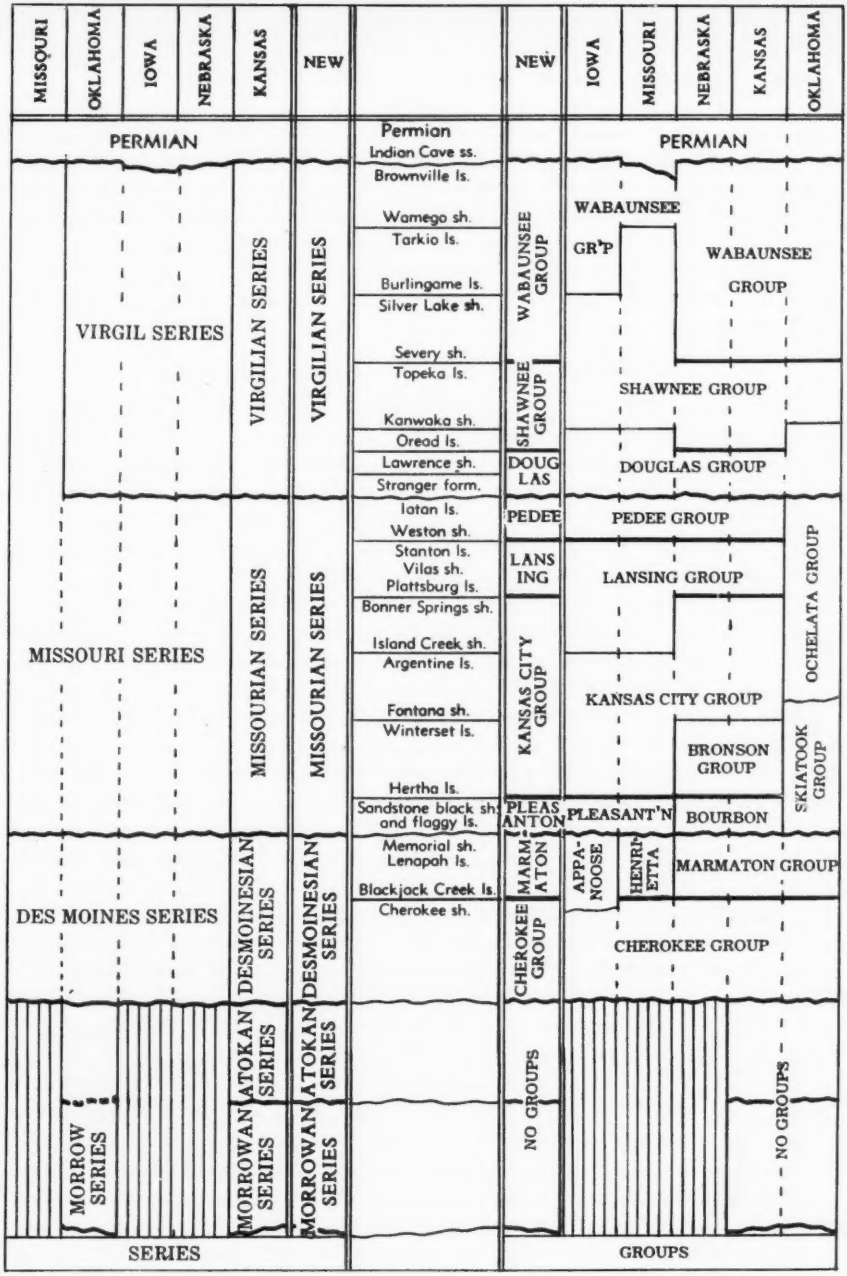


FIG. 1.—Series and groups of Pennsylvanian System in northern Mid-Continent region. Columns designated as "new" indicate classification accepted by inter-state agreement (except Atokan and Morrowan, which were not considered). Classifications in use by surveys of several states shortly prior to May, 1947, are shown in columns at left and right. Oklahoma has designated units like Missouri and Virgil as subseries (Oakes, 1940) and more recently as series (C. A. Moore, 1947). Oklahoma uses Des Moines Series as extending downward to top of Morrowan beds.

Missourian disconformity and a similar break occurring just above the horizon of the Brownville limestone, which in the northern Mid-Continent area is recognized to define the Pennsylvanian-Permian boundary, are classified as the Virgilian Series. They are characterized by invertebrate faunas of intermediate nature between those of the Missourian and Lower Permian and are classed as composing the upper part of the zone of *Triticites*.

The inter-state conference has adopted Virgilian Series with limits here indicated (Fig. 1).

ROCK UNITS—GROUP, SUBGROUP, FORMATION, MEMBER, BED

General considerations.—The succession of stratified deposits belonging to respective major time-rock divisions, classed as series, is each composed of varied sedimentary materials, partly marine and partly non-marine. The lithologic characters provide basis for classification that serves requirements for geological description and mapping. The named rock units are ranked as groups, formations, and members; two of the Pennsylvanian groups are divided into subgroups and there are a few named beds, subordinate to members.

Evidence of cyclic sedimentation is varyingly clear throughout the Pennsylvanian System in all the northern Mid-Continent region, but only in minor degree and rather exceptionally do boundaries of cyclothems coincide with the limits of rock units defined as members or formations. Reason for this is that precise delimitation of individual cyclothems in most places is impossible, either because the nature of well exposed beds between adjacent cyclothems does not afford conclusive indication of a boundary, or because critical parts of the section are concealed. Accordingly, the recognized rock units comprise lithologic entities having clearly marked physical limits, identification of which almost any two or more geologists can agree on readily. Commonly, these boundaries are well expressed topographically.

The general basis for differentiating an assemblage of beds classed together as a formation or group is dominance of a particular type of rock, at least in the area of the type section. Thus, a limestone formation, such as the Stanton, is composed predominantly of limestone members that are separated by thin shale members. A shale formation normally consists mostly of shale, but it may contain subordinate limestone or sandstone or both, and laterally the shale may diminish in importance as other rocks increase, until designation of the unit as a shale is no longer reasonable. The stratigraphic name may be retained because equivalence of span is definitely the same. The type Cherryvale shale section lacks limestone beds, whereas Cherryvale strata in Nebraska (as defined by interstate classification) consist mostly of limestone. Likewise, two or more successive formations that stand apart from adjoining parts of the column because of contrasting lithologic features, topographic expression, and other attributes, may be defined as groups. The Shawnee group, characterized by relatively thick, escarpment-forming limestones, differs markedly from the underlying Douglas group and overlying Wabaunsee group.

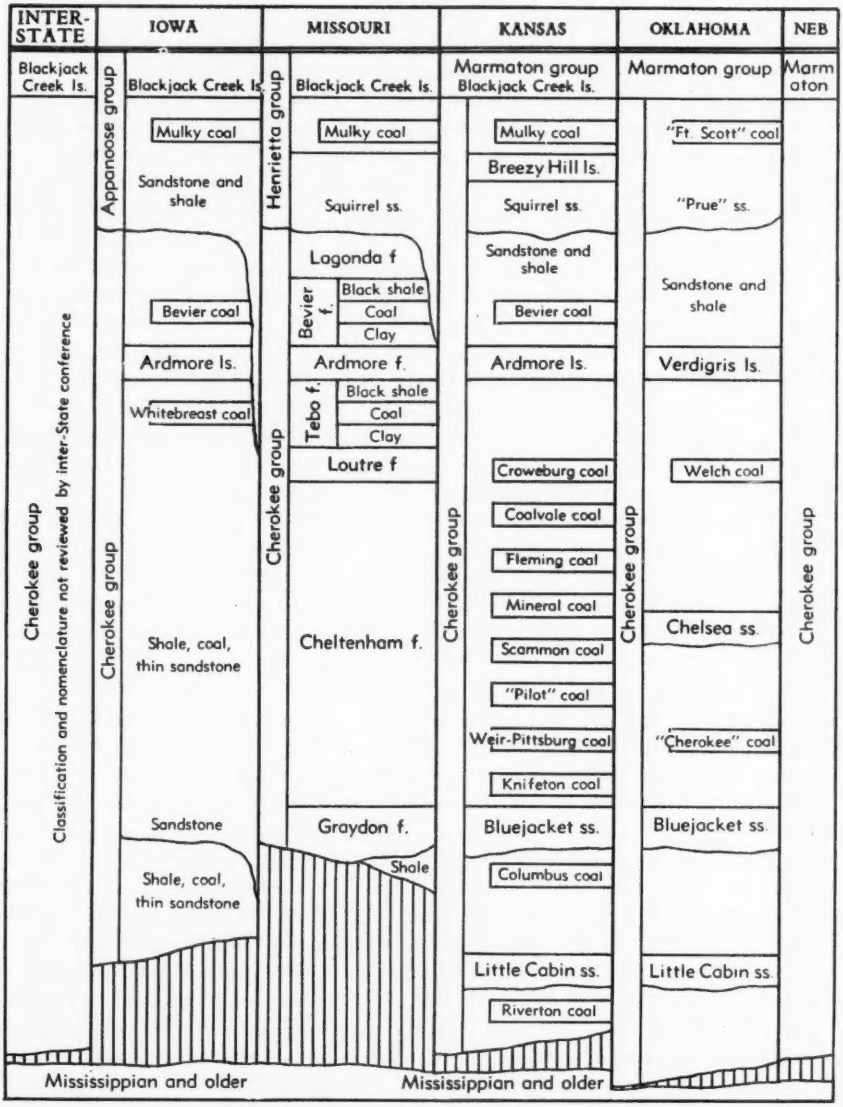


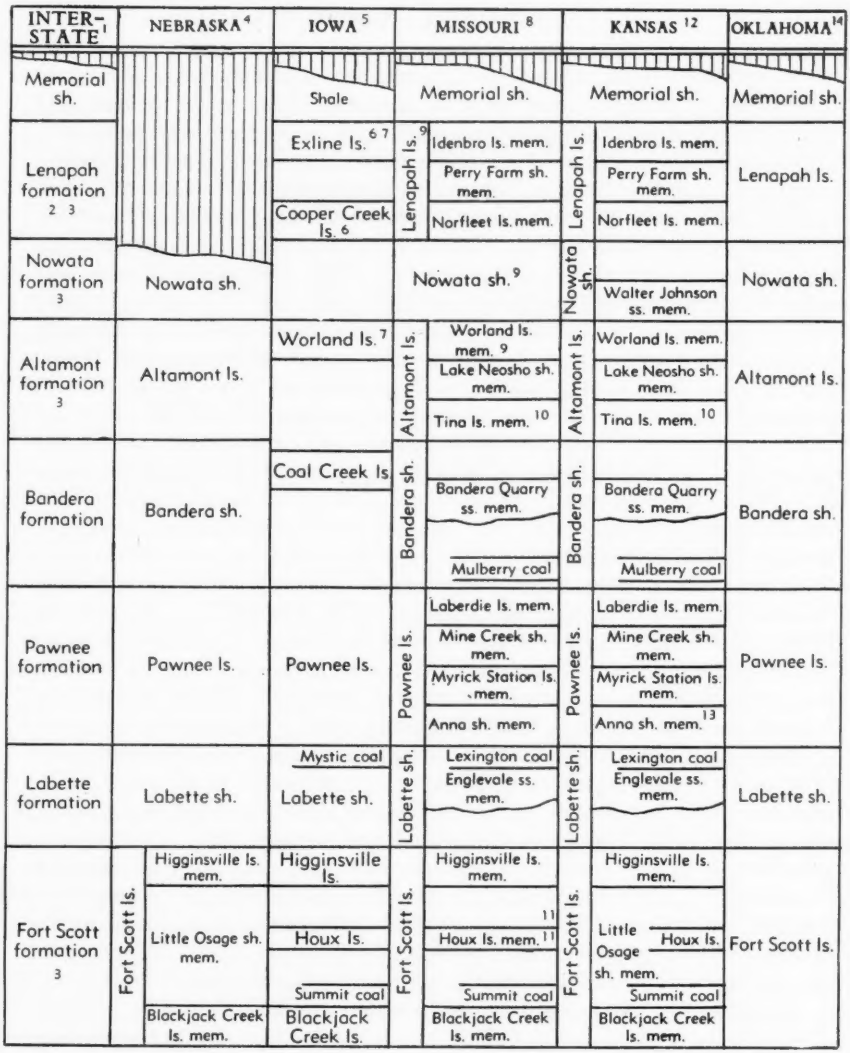
FIG. 2.—Classification of lower Desmoinesian rocks in northern Mid-Continent region. Column farthest left shows span accepted by inter-state conference for Cherokee group. Other columns partly indicate classification of Cherokee deposits recognized in several states shortly before May, 1947, conference. Placement of stratigraphic units in columns (excepting Ardmore and Verdigris limestones, Mulky, Fort Scott, and Bevier coals, Graydon, Bluejacket, and Little Cabin sandstones) does not indicate correlation. For Welch coal in Oklahoma column, read Broken Arrow coal.

Megacyclothem relationships (Moore, 1936, pp. 26–38), as well as occurrence near together of similar kinds of rock layers, are now understood as having importance in classifying the Mid-Continent Pennsylvanian deposits. For example, persistent thin limestone beds that characteristically underlie black platy shale are properly associated with limestone overlying the black shale, rather than treated as a minor element of a shale formation that includes the black shale.

Revision of nomenclature as source of instability.—Analysis of papers dealing with Pennsylvanian stratigraphy of the northern Mid-Continent area or touching on this phase of regional geology shows that few names, other than those applied to smallest rock units, have been employed with uniformity of definition throughout the years in which they have been used. This instability of nomenclature is partly an expression of progress in evolving an altogether suitable classification that may be employed in a large territory, but it is also baneful. As already stated, emendation of stratigraphic names makes for confusion. Even though it conserves by retaining old names, such retention with revised meaning is acceptable only if there is virtually complete agreement on use of the old term in an emended sense. The conference of State geological surveys has agreed to some emendations of stratigraphic names but none are radical and it is judged that the fact of inter-state agreement will stabilize the modifications which are indicated.

Lithologic designation of formations.—The classificatory terms best suited for application to many Pennsylvanian rock units of formation rank are not easily chosen. Long-adopted practice in some quarters has been to employ a lithologic term, based on the dominant type of rock contained in a unit, ignoring the presence and nature of subordinate constituents. For example, the so-called Oread limestone, which is classed as a formation, is composed of alternating limestone and shale which are designated as members (Fig. 5). In the type section, on and near the University of Kansas campus at Lawrence, limestone makes up approximately 60 per cent of the formation and shale the remaining 40 per cent. Owing to resistance of the limestone to erosion, the outcrop of the Oread beds is marked by a prominent escarpment. Designation of the Oread as limestone calls attention to lithologic constituents which are deemed to be most important, and many geologists hold that it is decidedly better to convey such information in stratigraphic nomenclature than to use the wholly non-committal term "formation" for lithologically composite successions of strata which are treated as map units called formations. Undoubtedly, there is merit in this view. Few will argue that a stratigraphic unit of formation rank having 99 per cent of one kind of rock and 1 per cent of other should be called "formation," simply because of its lithologically composite nature. If we followed such a course, it would be hard to find many formational units to which we could apply terms such as sandstone, shale, or limestone. Sedimentary deposits vary in composition almost universally both in vertical and lateral directions.

Suppose the dominant and subordinate constituents of a defined formational unit are respectively 90 per cent and 10 per cent; or 75 and 25; or 51 and 49.



[1] Classification and nomenclature of subdivisions of formations not reviewed by inter-state conference.
[2] Not recognized in Nebraska.
[3] Not recognized in Iowa.
[4] Condra and Reed (1943).
[5] Cline and Stookey (unpublished chart); Cline (1941).
[6] Correlation with Lenapah limestone not established.
[7] Recognized by Cline (1941) in northern Missouri, also; placed in Pleasanton by Clair (1943).
[8] Mainly based on unpublished chart by W. V. Searight (1948).
[9] McQueen and Greene (1938) report that Nowata and Lenapah beds are absent in Missouri and class Worland as subdivision of Bandera shale.
[10] Type Tina limestone is now known not to belong in Altamont; new name is to be substituted.
[11] Clair (1943).
[12] Moore, Jewett, and Frye (1944).
[13] Includes thin limestone at base.
[14] Newell (1937); Oakes and Jewett (1943).

FIG. 3.—Classification of upper Desmoinesian rocks in northern Mid-Continent region. Column at extreme left shows classification adopted for inter-state use. Other columns indicate classifications used in several states shortly before May, 1947, conference and intended for continued use therein excepting minor changes.

Can proportions be stipulated for determining classificatory nomenclature? Obviously, any such stipulation would be arbitrary, and to obtain agreement of geologists on quantitative guides for use of terms would be almost impossible. Yet we need to do something. Examples of current practice in nomenclature can be cited in which the "dominant" lithologic component of a so-called formation is 10–15 per cent and the "subordinate" component is 85–90 per cent. The Oread limestone and Caneyville limestone in parts of southern Kansas comprise strata among which limestone is actually a minor rock type. Designation of such units as limestone seems clearly inappropriate; the lithologic term is a misnomer. Shall we use "limestone" where this is the predominant rock of a formation and change to some other term, such as "shale" or "formation" where limestone is subordinate or perhaps lacking entirely? If changes of this nature are found, is it preferable to adopt an altogether different stratigraphic classification, in which units defined as formations have boundaries at horizons not equivalent to those separating formations in the abandoned classification? These are pertinent questions which become increasingly bothersome as effort is made to extend application of stratigraphic terms from one region into another and as the character of deposits is found to vary laterally.

It is my judgment that (1) properly defined formations in any area are differentiated on the basis of lithologic characters which are clearly defined and presumed to have most significance from several viewpoints; (2) stratigraphic units classed as formations are not indefinitely extended horizontally and are not to be interpreted as divisions of the sedimentary succession which are uniformly bounded below and above by time-equivalent planes; (3) lateral variation in the lithologic constitution of a defined formation beyond a point marking persistence of characteristic features of the type section imposes need to modify stratigraphic classification in such manner as best serves the ends of geologic mapping and description; and (4) formational units having two or more types of sedimentary rocks as important constituents are ordinarily best designated by the term "formation," rather than by one of the rock names for a single constituent, but it is desirable to use a lithologic designation for units composed predominantly of one kind of rock or containing a particular type of rock which for some good reason is deemed to outweigh other constituents in importance.

The matters of nomenclature just discussed were not reviewed by the interstate conference at Lawrence but have been the subject of subsequent correspondence. Some State geologists hold the view expressed in (4), above, but others are not ready to formulate a definite opinion. The classification shown in the "Inter-state" columns of Figures 2–6 designates most units of formational rank as "formations," but this does not signify agreement by the five State surveys to adopt such usage.

Cherokee group.—Northward from the approximate position of the Arkansas River in Oklahoma, deposits lying between the base of the Desmoinesian Series and base of the Blackjack Creek limestone (lowermost member of the Fort Scott

limestone) or equivalent horizon are assigned to the Cherokee group, named from Cherokee County, Kansas. Post-Morrowan beds that may be recognized also as pre-Desmoinesian are to be excluded from the Cherokee group. In Iowa and northern Missouri, where increase in thickness of shale next above the Blackjack Creek limestone may make it undesirable to recognize the Fort Scott limestone as a formation, the top of the Cherokee group is placed at the base of the Blackjack Creek limestone. There is a possibility that the Breezy Hill limestone, which occurs just below the Blackjack Creek limestone in southeastern Kansas and adjoining parts of Missouri and Oklahoma, should be classed as a member of the Fort Scott formation rather than a unit of the uppermost Cherokee, but reasons for making such change are not now evident.

Restriction of the Cherokee group by excluding deposits between the Blackjack Creek limestone and a prominent disconformity occurring a few tens of feet below this limestone in Iowa and Missouri (Cline, 1939, and column 31 of chart in Moore *et al.*, 1944; McQueen, 1943, pp. 90, 95) was agreed to be inadvisable (Figs. 1, 2).

The inter-state conference did not undertake to review classification and nomenclature of subdivisions of the Cherokee group. Accordingly, stratigraphic treatment of these units is not coordinated—indeed, present knowledge is far from sufficient to permit detailed correlations. Some units, like the Ardmore limestone (called Verdigris in northeastern Oklahoma) and Mulky coal, seem to be identifiable from Oklahoma to Iowa, but local variations of the sedimentary succession may well be such that a uniform classification of Cherokee strata in the northern Mid-Continent states is inappropriate.

Marmaton group.—Strata from the base of the Fort Scott limestone (or Blackjack Creek limestone) to the disconformity that marks the upper limit of the Desmoinesian Series are designated as the Marmaton group (Figs. 1, 3). This name has been used generally in the sense here indicated during many years in Kansas, northeastern Oklahoma, and Nebraska, being employed extensively in subsurface nomenclature as well as in classification of outcropping beds. The term Henrietta group, which was formerly applied to beds from the base of the Fort Scott limestone to the top of the Pawnee limestone, has been used recently in Missouri (McQueen and Greene, 1938; Grohskopf, Hinchey, and Greene, 1939; Clair, 1943) and Iowa (Cline, 1941) as an exact synonym of Marmaton, but Cline (1939) and McQueen (1943, p. 90) altered the stratigraphic span of Henrietta by including in it upper beds of the Cherokee, as previously classified. This name is now abandoned by action of the inter-state conference, both because in common later usage it duplicates Marmaton and because formations overlying the Pawnee limestone are not well developed near Henrietta. The name Appanoose, which was introduced by Bain (1896) for deposits in Iowa that approximate the span of the Marmaton group, was used by Cline (column 31 of chart in Moore *et al.*, 1944) for upper Desmoinesian beds, classed as a group, extending downward to a somewhat prominent disconformity that is recognized in Iowa between the Ardmore

and Blackjack Creek limestones. Thus, the Appanoose includes some upper Cherokee strata and corresponds to Henrietta group as treated by Cline in 1939 (p. 1905) and as redefined by McQueen (1943). The Iowa and Missouri geological surveys now join with Kansas, Nebraska, and Oklahoma in recognizing the Marmaton group (Figs. 1, 3). Although Marmaton deposits are very well developed in northeastern Oklahoma, there is possibility (R. H. Dott, personal communication) that this name, as applied to a group, may not be recognized in classification adopted for the new Oklahoma geological map.

Classification of Marmaton rocks has differed in a few features in the different states (Fig. 3) and it continues to lack complete uniformity. The divergence that exists is largely a reflection of stratigraphic differences. For example, the assemblage together of limestones and shales from Blackjack Creek to Higginsville limestones, inclusive, so as to make the unit called Fort Scott formation, is judged to be unnatural in Iowa; accordingly, Fort Scott is not recognized and the rock divisions which are classed as members of the Fort Scott in Missouri and Kansas are treated in Iowa as independent formational units. The Coal Creek limestone is found in northern Missouri and Iowa but has not been identified in western Missouri, Kansas, and northeastern Oklahoma. Relations of the Cooper Creek and Exline limestones to the Lenapah formation are undetermined. Marmaton strata are buried in Nebraska.

Pleasanton group.—Lowermost deposits of Missourian age, mostly of clastic nature, are to be called Pleasanton, a name first used in a stratigraphic sense by Haworth (1895) for rocks between the uppermost Pawnee limestone and base of the Hertha formation. Pleasanton was similarly used in Missouri until 1938 (McQueen and Greene) when it was revised to exclude Desmoinesian strata. In Kansas (Moore, 1932) and Nebraska (Condra, 1935) the name was dropped.

Despite previous variation in the span of beds defined as Pleasanton, agreement of the surveys at the Lawrence conference should stabilize future application of this name to the interval from the basal Missourian disconformity to the base of the Hertha formation. The now-accepted definition, which was first used by McQueen and Greene (1938), precisely corresponds to Bourbon formation or group as recognized in Kansas and Nebraska. Priority in application to the stratigraphic span that here is assigned to the revised Pleasanton and consistency in numerous publications make Bourbon preferable to Pleasanton, but the latter name has been accepted in the interest of obtaining uniform inter-state nomenclature. It is deemed acceptable on the basis of the unanimous agreement as to the revised definition. The name Bourbon, considered by some to be historically anomalous in "arid" Kansas, will be suppressed. The Pleasanton deposits are classed as a group.

Kansas City group.—A revised definition of the Kansas City group was agreed to by the State geological surveys of Iowa, Kansas, Missouri, and Nebraska (Figs. 1, 4); this term is not applicable to Missourian deposits in Oklahoma. As adopted by the conference, the lower boundary of the group is placed at the base of the Hertha formation and the upper boundary is drawn at the base of the Plattsburg

formation (Figs. 1, 4). This modifies the originally designated limits (Hinds, 1912, p. 7) by addition of the "Lane shale" of Missouri usage (Island Creek shale, Farley limestone, and Bonner Springs shale) at the top of the group, and to the same extent changes usage that has been followed by the Missouri Geological Survey since 1912. The newly agreed upper boundary of the Kansas City group coincides with definition of this line that has been employed during the past 15 years in Kansas (Moore, 1932) and Nebraska (Condra, 1935), but the lower limit of the group (top of the Dennis formation) used by the Kansas and Nebraska geological surveys in recent years differs from the definition accepted by the conference, which follows original Missouri Survey usage and that followed in Iowa. Subdivisions of the Kansas City group, as previously defined and as now recognized, are shown in Figure 4.

The term Kansas City, especially in combination with the overlying Lansing, as Kansas City-Lansing, has been very widely used by geologists in the northern Mid-Continent for designation of subsurface beds extending from Hertha to Stanton. Surface nomenclature adopted by the surveys thus accords with that which has come to be accepted as best suited to subsurface requirements.

The strata included in the Kansas City group are judged to be divisible advantageously into three main parts of subequal thickness, which are treated as subgroups. In upward order, these are called Bronson, Linn (new), and Zarah (new). They differ in dominant lithologic characteristics and are bounded by exceptionally persistent marker beds.

Bronson subgroup.—The lower main division of the Kansas City group, as now defined, consists of the old "triple limestone" (Haworth, 1895a, p. 458), which was named Bronson by Adams (1904). It extends from the base of the Hertha formation to the top of the Dennis formation (Fig. 4). Along the outcrop from central eastern Kansas into Iowa, the Hertha, Swope, and Dennis formations are respectively separated by relatively thin shales and they form a well defined escarpment that rises above the Pleasanton lowland belt. The uppermost Bronson unit (Winterset limestone) extends as far southward as T. 8 N. in Oklahoma, some 60 miles south of Tulsa, but the Hertha disappears before the Kansas-Oklahoma state line is reached. Where the normal lower boundary of the subgroup (and group) can be followed no longer, classification must be modified by reducing the stratigraphic span so as to include only units that can be recognized and traced, or nomenclature suited to northern territory must be discarded in favor of different terminology that is adapted to southern Kansas and northeastern Oklahoma. The latter course has been followed. South of the point where the Hertha disappears, lower Missourian deposits are referred to the Skiatook group and they are named, in upward order, Seminole formation, Checkerboard limestone, Coffeyville formation, Dennis formation, Cherryvale shale, and Drum limestone. The Oklahoma Geological Survey is disposed to retain Hogshooter (instead of Dennis) and to use Dewey as a formation name, rather than as a member of the Drum limestone.

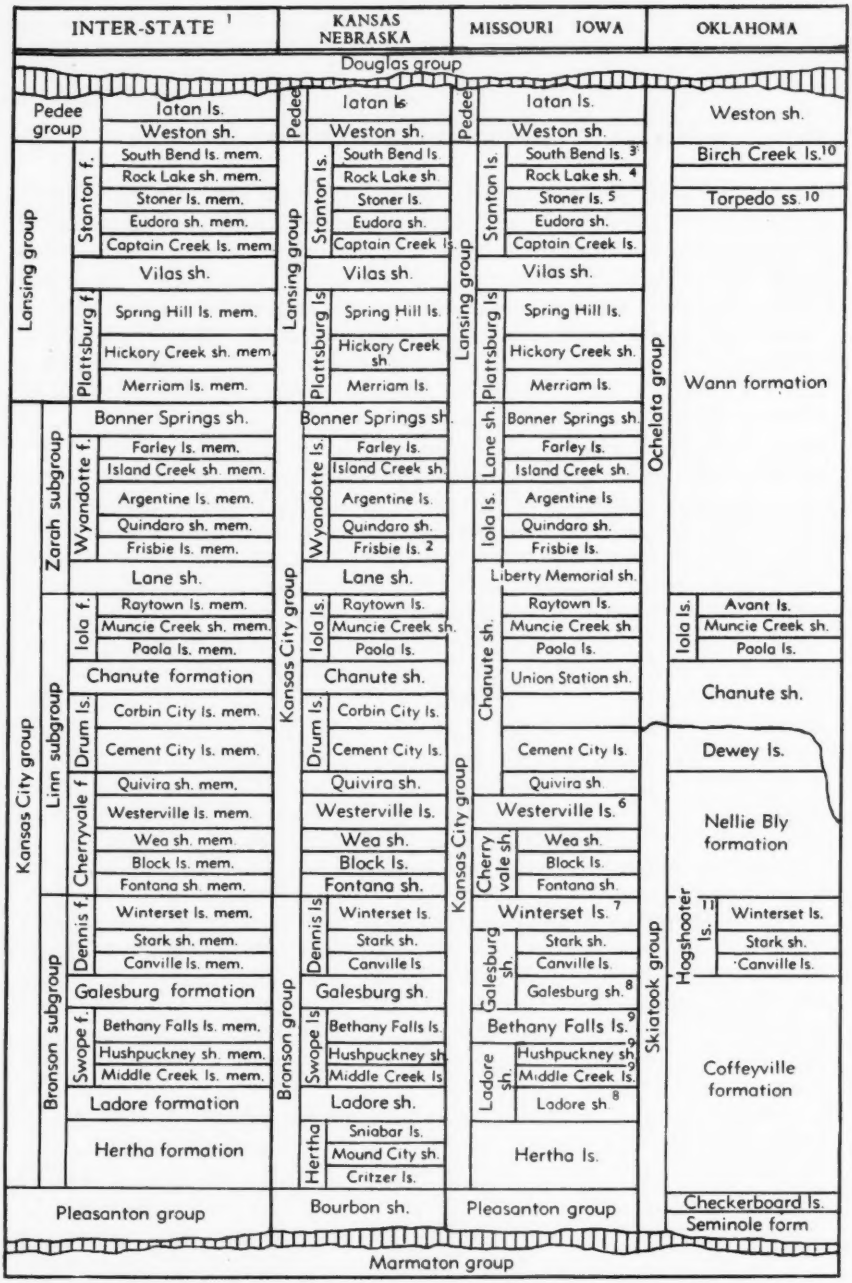
Linn subgroup (new).—The middle part of the Kansas City group, from the

base of the Cherryvale formation to the top of the Iola formation, is defined as the Linn subgroup, named from Linn County, Kansas, which contains excellent exposures of all constituent units (Fig. 4). The subgroup is characterized by relative prominence of shale, but there are persistent limestones that mostly are only a few feet thick; locally there is much sandstone. A disconformity of more than ordinary prominence occurs within the Linn subgroup (at the base of the Chanute formation) and at several places it extends downward to or into the Bronson beds. The fact that no seemingly significant faunal change is associated with this break supports interpretation of the disconformity as lacking any special importance for separation of time-rock units. It is considered to indicate somewhat unusual physical changes incident to the close of one cyclothem (Drum) and the beginning of the next (Iola). In southern Kansas and northeastern Oklahoma, however, this disconformity is designated as the boundary between the Skiatook group, below, and the Ochelata group, above.

The *Cherryvale formation* named from southern Kansas (Haworth, 1898, p. 47) includes strata from the top of the Winterset limestone to the base of the Drum limestone. At the type locality of the Cherryvale, the section consists entirely of shale, but farther north there are persistent limestones (Block, Westerville) that extend into Iowa and Nebraska. These limestones and the shale subdivisions lying below and above them may be classed as members of the Cherryvale (Fig. 4).

The *Drum limestone* in its type area near Independence, Kansas, comprises conspicuously distinct parts that are classed as members. The upper unit is predominantly a cross-bedded oolite that is locally 40 feet or more in thickness but is not persistent; it is known as the Corbin City limestone member. The Corbin City disconformably overlies the lower member which consists of fine-grained bluish limestone; this is identified unquestionably as the Dewey limestone (Ohern, 1910, p. 30) of northeastern Oklahoma. Northeastward tracing proves that the Dewey member of the Drum is the same as the limestone called Cement City in the Kansas City area. Inasmuch as Dewey has priority over Cement City (Hinds and Greene, 1915) and has been widely used, it is recognized by the Oklahoma Geological Survey as a formational unit, which is classed as the uppermost division of the Skiatook group. The Kansas Geological Survey has used the name Cement City for the lower member of the Drum limestone (Moore, 1932; Moore, Jewett, and Frye, 1944), and Cement City was recognized by the inter-state conference. Kansas proposes to deviate from the inter-state classification by adopting Dewey, instead of Cement City, because survey geologists are convinced of the identity of type Dewey and the lower limestone member of the type Drum limestone. The discrepancy involved in use of Cement City by other state surveys is not serious and it is reasonable that they continue to recognize Cement City until question of stratigraphic identity of the type of this unit (near Kansas City) and the Dewey is removed.

Oklahoma's position in connection with use of Dewey and Drum is theoreti-



[1] Recognition of subgroups of Kansas City is optional. Also, units such as Stanton, Plattsburg, Chanute, and others having composite lithologic characters, may be designated as formations or as limestone, shale, *et cetera*, according to predominant type of constituent rock.

[2] Frisbie limestone not recognized in Nebraska.

[3] Called South Bend or Little Kaw limestone by McQueen and Greene (1938).

[4] Called Rock Lake or Victory Junction shale by McQueen and Greene (1938).

[5] Called Stoner or Olathe limestone by McQueen and Greene (1938).

[6] Westerville limestone included in Cherryvale shale by Clair (1943).

[7] Winterset limestone classed as members of Dennis limestone by Clair (1943).

[8] Galesburg and Ladore shale classed both as formation and member by McQueen and Greene (1938).

[9] Bethany Falls, Hushpuckney, and Middle Creek classed as members of Swope limestone by Clair (1943).

[10] Oakes (1940); stratigraphic placement of beds above Wann formation uncertain.

[11] Oakes (1940) includes Lost City limestone member locally instead of Stark and Canfield, but in many places only Winterset member is present.

FIG. 4.—Classification of Missourian rocks in northern Mid-Continent region. Column at extreme left shows classification adopted by inter-state conference of May, 1947, with proviso that some differences may be required by regional variation of minor stratigraphic units; also, it is recognized that classification of Missourian strata in northern Oklahoma necessarily diverges from inter-state usage and will probably be modified in some features by future study.

cally the same as that of Kansas, for geologists of both State surveys agree on equivalence of type Dewey and the fine-grained bluish limestone of the lower Drum, which disconformably underlies the locally thick oölitic to conglomeratic upper Drum (Corbin City member). Inasmuch as Drum (Adams, Girty, and White, 1903) has priority of definition and probably a good deal more widespread usage than Dewey, the limestone at the Dewey Portland cement quarry and equivalent beds elsewhere in Oklahoma should be called Drum limestone (Dewey limestone member). The Corbin City member of the Drum is interpreted by Oakes (1940, p. 56) as possibly equivalent to conglomeratic limestone which he classed as basal Chanute and included in the Skiatook group.

Miscorrelation of the *Iola formation* by Haworth and Bennett (1908) in tracing limestone in this part of the section northeastward to Kansas City has been responsible for longstanding error in nomenclature of Missourian units in northeastern Kansas and northwestern Missouri. The Drum limestone was misidentified at Kansas City also; the supposed Drum, as identified in reports issued prior to 1932, is now known to be the Westerville limestone (Bain, 1898), named from Iowa. Work mainly by N. D. Newell (Moore, 1932) served to show that the Iola limestone is actually represented at Kansas City by beds called Paola, Muncie Creek, and Raytown. The "Iola limestone" of Haworth and Bennett in the Kansas City area was renamed by Newell (Moore, 1932) (Frisbie limestone, Quindaro shale, Argentine limestone). Appropriate revision of classification which was adopted by Kansas and Nebraska was not accepted by Missouri (McQueen and Greene, 1938; Clair, 1943) until the field conference of May 6, 1947, when Clark, Greene, and Searight, after step-by-step review of outcrops between Kansas City and Iola, accepted the identity of the Paola-to-Raytown and the type Iola sections.

The Iola formation is well developed in northeastern Oklahoma (Oakes, 1940) where it is divided into the Paola, Muncie Creek, and Avant members. The Avant limestone (Ohern, 1910) occupies the stratigraphic position of the Raytown limestone (Hinds and Greene, 1915) but lithologic dissimilarity, which indicates different cyclic relationships, suggests that these two units are not necessarily synonymous. For the present, the northern Mid-Continent states, except Oklahoma, retain Raytown.

Settlement of the "Iola problem" has led automatically to a number of changes in the Missouri Survey's classification of middle and upper Kansas City beds so as to bring inter-state agreement in nomenclature (Fig. 4). 1. The Union Station shale (Clair, 1943) member of the Chanute formation is suppressed because it is a synonym of Chanute as a whole. 2. The Cement City limestone, previously classed as a member of the Chanute shale, is recognized as representative in the Kansas City area of the Drum limestone. (The Missouri Geological Survey retains the name Cement City for this unit.) 3. The Paola limestone, Muncie Creek shale, and Raytown limestone, which were treated as members of the Chanute shale, are recognized as belonging to the Iola formation. 4. The Liberty

Memorial shale (Clair, 1943), overlying the Raytown limestone, is no longer considered as uppermost member of the Chanute shale. This name is suppressed as a junior synonym of Lane shale. 5. The Frisbie limestone, Quindaro shale, and Argentine limestone, which were indicated as members of the Iola limestone in western Missouri, are classified with the overlying Island Creek shale and Farley limestone as members of the Wyandotte formation. 6. The Island Creek shale and Farley limestone, which were associated with the overlying Bonner springs shale as members of the Lane shale, are included in the Wyandotte formation. 7. The Bonner Springs shale is recognized as a formational unit between the Wyandotte and Plattsburg formations.

Zarah subgroup (new).—The upper part of the Kansas City group, comprising approximately one third of the section, is designated as the Zarah subgroup, named from the village of Zarah on Kansas Highway 10 at the Sante Fe Railway crossing in western Johnson County. The subgroup includes beds between the top of the Iola formation and base of the Plattsburg formation (Fig. 4). Near Kansas City, this interval is mainly characterized by prominent limestone members of the Wyandotte formation, occurring between the relatively thin Lane shale and Bonner Springs shale, which comprise the lower and upper parts of the subgroup, respectively. The thickness of subdivisions varies greatly from place to place. The Wyandotte extends northward into Iowa and Nebraska but southwestward from Kansas City it becomes thinner and the underlying Lane shale thicker. In eastern Anderson County, the Wyandotte is locally absent and in northern Allen County it is found to grade laterally into calcareous ripple-marked sandstone. Where the Wyandotte is missing, there is a virtually indivisible shale section between the Iola and Plattsburg formations and this shale is termed Lane-Bonner Springs shale. As a shale unit, the Zarah portion of the Kansas City group can be followed southward to Montgomery County, nearly but not quite to the Oklahoma line.

Lansing group.—As originally defined (Hinds, 1912, p. 7), the name Lansing was applied to strata from the top of the so-called Iola limestone (Frisbie-Argentine of present classification) in the Kansas City area to the top of the Stanton limestone. The overlying shale (Weston) was thought to be a part of the Douglas "shale." The Lansing beds were designated as a formation and divided into members termed (in upward order) Lane shale (now recognized as Island Creek shale, Farley limestone, and Bonner Springs shale), Plattsburg limestone, Vilas shale, and Stanton limestone. When work by Condra (1927), Newell (1935) and others led to subdivision of the Plattsburg and Stanton units into persistent limestone and shale components that were classed as members, it became necessary to treat Plattsburg, Vilas, and Stanton as formations and to change Lansing formation to Lansing group. Moore (1932) revised the assigned span of the Lansing group by transferring beds below the Plattsburg to the Kansas City group. The Plattsburg-to-Stanton division placed in the revised Lansing group is characterized by dominance of limestone and along most of the outcrop the

Lansing limestones lie closely together, forming a prominent escarpment that is widely separated from escarpments made by lower and higher limestones. The inter-state conference accepted definition of the Lansing group as emended by Moore, that is, consisting of the Plattsburg, Vilas, and Stanton formations (Fig. 4).

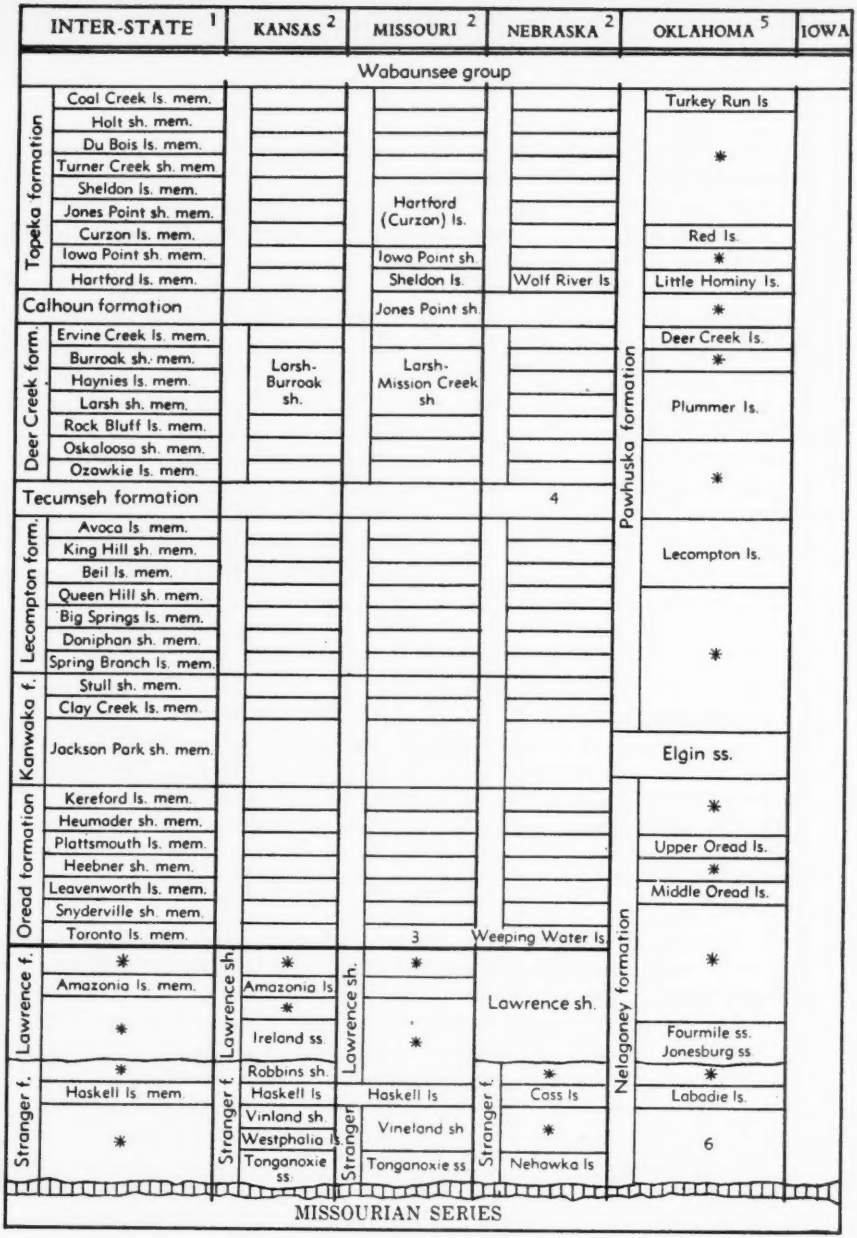
Pedee group.—In the vicinity of the Kansas River, deposits of Virgilian age rest directly on upper beds of the Lansing group, but to the north and south there are post-Lansing strata of variable thickness that belong to the Missourian Series. These rocks are assigned to the Pedee group (Figs. 1, 4). They lie conformably on the Stanton formation and are bounded above by the disconformity that divides Missourian and Virgilian deposits. The lower part of the Pedee group is called Weston shale, and the upper part, which is definitely recognized only north of Kansas River, is named Iatan limestone. Shale and sandstone of post-Iatan Missourian age may occur in some places but this is uncertain.

Douglas group.—Haworth (1898, p. 93) introduced the term Douglas for the predominantly shale and sandstone deposits occurring between the top of the Stanton formation and top of the Oread formation. The Oread is one of the best-marked escarpment makers in the Pennsylvanian succession of the northern Mid-Continent and it is natural that this escarpment should be chosen as marking an important stratigraphic boundary. The line mapped by Haworth and his associates to show distribution of the Oread follows the escarpment front and coincides with the base of the lowermost limestone. Inasmuch as the Oread commonly makes a broad dip slope, the contact between the upper limestone and overlying shale (Kanwaka) is a topographically inconspicuous line that in many places is several miles west of the escarpment front. Partly on cartographic grounds but more on the basis of lithologic characters and megacyclothem relationships which call for associating the Oread beds with Lecompton, Deer Creek and Topeka beds, Moore (1932) redefined the stratigraphic span of the Douglas group to exclude both upper Missourian deposits (Weston, Iatan) and the Oread formation.

As now recognized and accepted by the conference, the Douglas group comprises the strata, almost exclusively clastic, occurring between the disconformity at the base of the Virgilian Series and the base of the Oread formation (Figs. 1, 5). Lateral variations in the nature of the Douglas deposits naturally impose differences in local classification and it is not intended to exclude such differences as may be judged needful in the several states. For example, the Westphalia limestone is now recognized only in parts of southeastern Kansas, and the Nehawka limestone seems to be a local deposit in Nebraska.

Where the disconformity that marks the boundary between Missourian and Virgilian beds is not identifiable in wells, the clastic deposits between the Stanton and Oread limestones may be termed Pedee-Douglas.

Shawnee group.—Based largely on prominence of relatively thick limestone formations that show remarkably developed megacyclothem features, as de-



[1] In the inter-state column, not all subdivisions, particularly in Douglas group, are recognized in Missouri, Nebraska, Oklahoma, and Iowa.

[2] Classification same as inter-state excepting as shown.

[3] Called Toronto or Weeping Water limestone by McQueen and Greene (1938).

[4] Tecumseh shale in Nebraska is divided into members, in upward order: Kenosha shale, Ost limestone, Rakes Creek shale.

[5] Classification not yet adequately investigated or reported in publications of State Geological Survey. Many Shawnee units have been identified, but correlation of some with stratigraphic units in Kansas and other states is not definitely known.

[6] Shale and sandstone, including Cheshewalla sandstone, and possibly Revard and Bigheart sandstone.

* Subdivision unnamed.

FIG. 5.—Classification of lower and middle Virgilian rocks in northern Mid-Continent region. Column at extreme left shows agreed inter-state classification which is subject to modifications imposed by lateral variations of deposits. Other columns indicate previous usage in several states. Some deviations shown, especially in Douglas group, will persist. In northern Oklahoma there are unsettled questions of classification and nomenclature.

scribed by Moore (1936, p. 29), the Shawnee group has been defined (Moore, 1932) as extending from the base of the Oread formation to the top of the Topeka formation (Figs. 1, 5). This stratigraphic span has been recognized uniformly in reports of the Kansas and Nebraska geological surveys and in many other papers during the last 15 years but until recently it has not been accepted by the Missouri and Iowa geological surveys.

The inter-state conference recognizes classification of the Shawnee group as shown in Figure 5, but it is agreed that where stratigraphic variation calls for omission or combination of stratigraphic terms, appropriate adjustment of nomenclature is to be employed. The persistence of most stratigraphic units and the surprising uniformity displayed throughout their known area of distribution in Iowa, Missouri, Kansas, and Nebraska permit exceptional uniformity in classification and nomenclature. Problems are introduced, however, near the Kansas-Oklahoma boundary owing to southward change of facies. Additional detailed studies are needed both in southern Kansas and northern Oklahoma and in this area, classification deemed to be most appropriate is yet to be worked out.

Wabaunsee group.—The Wabaunsee group was originally defined (Prosser, 1895) as a formation extending from the Nodaway coal in the Howard formation to the base of the Cottonwood limestone. It has been revised by addition of lower strata down to the top of the Topeka formation (Moore, 1931) and by elimination of the upper part of beds classed as belonging in the Permian System (Moore and Moss, 1934; Condra, 1935; Moore, 1936). Virtually all usage of Wabaunsee published during the last 15 years recognizes the upper boundary as drawn at the prominent disconformity just above the Brownville limestone (Fig. 1).

The Wabaunsee group consists of numerous thin but very persistent stratigraphic units, most of which maintain remarkably uniform lithologic and faunal characteristics along outcrops extending from northern Oklahoma to Nebraska and Iowa.

The inter-state conference has recognized as standard the classification which has been developed mainly in Kansas and Nebraska, but it is agreed that nomenclature in the several states may be required to deviate from this by combination or omission of terms where certain named rock units are not recognizable. This classification, with annotations referring to the different northern Mid-Continent states, is shown in Figure 6. The subgroups called Sacfox, Nemaha, and Richardson, which have been defined in Nebraska (Condra and Bengston, 1915; Condra, 1935) are included in the inter-state classification but use of them is not mandatory. This follows partly from the fact that units like the Tarkio limestone and Burlingame formation, which mark boundaries between the subgroups, are extremely inconspicuous or unrecognizable in parts of the Mid-Continent area. Thus, the Tarkio limestone cannot be identified south of Emporia, Kansas, although it is followed very readily in areas farther north.

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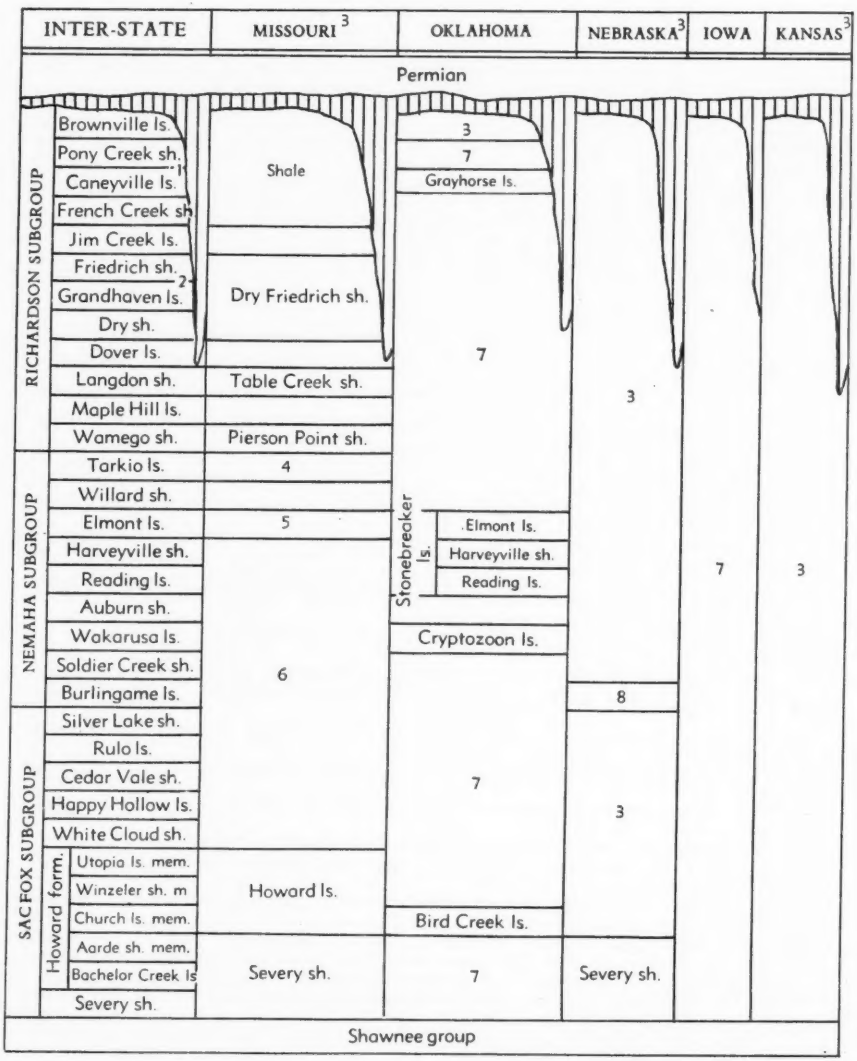

[1] Or Wood Siding formation, including in upward order, Nebraska City limestone, unnamed shale, Pony Creek shale.
[2] Or, in upward order, Morton limestone, Minersville shale, Palmyra limestone, Otoe shale.
[3] Classification same as inter-state, excepting as shown.
[4] Tarkio limestone has been indicated as basal division of the Wabaunsee group in Missouri (Hinds and Greene, 1915; McQueen and Greene, 1938).
[5] Called Elmont or Preston limestone by McQueen and Greene (1938).
[6] Beds between Howard and Elmont limestone called Scranton by Hinds and Greene (1915).
[7] Units incompletely differentiated and identified.
[8] Nebraska recognized members of Burlingame limestone, in upward order, Taylor Branch limestone, Winnebago shale, South Fork limestone.

FIG. 6.—Classification of upper Virgilian rocks in northern Mid-Continent region. Column at extreme left shows agreed inter-state classification, which is subject to deviations (mainly by hyphenated grouping of minor stratigraphic units) in several states as required by lateral variations of deposits. Other columns indicate stratigraphic divisions previously recognized.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2041-2062, 14 FIGS.

DEEP DRILLING AND DEEPER OIL POSSIBILITIES IN ILLINOIS[1]

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Urbana, Illinois

ABSTRACT

During the 4 years, 1944 to 1947, sixteen oil test wells were drilled in Illinois to the St. Peter sandstone, of which thirteen penetrated to various formations below the St. Peter, two reaching the basement rocks.

Isopach maps of various formations between the St. Peter sandstone and the basement rocks, supplemented with cross sections, show the influence of the Ozark and Wisconsin positive structural areas. Notable variations in the stratigraphic sequence are the disappearance of the Galesville sandstone and the introduction of an oölitic limestone in the Cambrian strata in central Illinois.

Maps show the structure of the Illinois basin on the top of the St. Peter sandstone and the general configuration of the basement surface so far as known. Isocons on the St. Peter map show the total mineral content of water in the St. Peter sandstone.

Some of the geological factors that should be considered in prospecting for oil in these deep strata are discussed.

The geological situation with regard to the possibilities of obtaining oil by deeper drilling in Illinois was reviewed by the Illinois Geological Survey in an article published in the early part of 1944.[3] Since that time 16 wells have been drilled in Illinois to test for oil in the St. Peter or deeper formations. Thirteen of these wells tested below the St. Peter and two reached the basement rocks. These tests were at scattered locations along the west side of Illinois from Madison to Hancock counties and in central to northern Illinois from Douglas to Lee counties. No oil was obtained but it may be of value to summarize for the benefit of further prospecting the geologic information now available.

Figure 1 shows the locations of two geologic cross sections, *AB* and *CD*, drawn through 15 wells. One extends north-northwestward from St. Louis to southern Hancock County, thence northeastward to northeastern DeKalb County. The other extends northeastward from southwestern Jersey County to Kankakee County, excepting that well 12 is a little more than 40 miles southeast of the general line of section. The top of the Glenwood-St. Peter sandstones is the datum from which the succession of strata are shown to extend downward in the cross sections.

MT. SIMON-FOND DU LAC (?) SANDSTONES

The Fond du Lac (?) is an incoherent sandstone at the base of the sedimentary series in Illinois. It consists of very fine- to very coarse-grained, pink, yellow, and white sand grains that are somewhat rounded. The Fond du Lac (?) constitutes most of the Mt. Simon-Fond du Lac (?) succession, and is very difficult to sepa-

[1] Read at the Eastern Interior regional meeting at St. Louis, January 15, 1948. Manuscript received, June 29, 1948. Published by permission of the chief of the Illinois State Geological Survey.

[2] Illinois State Geological Survey.

[3] Stewart Folk, "Lower Ordovician and Cambrian Oil Possibilities in Illinois," *Oil Weekly* (March 20, 1944), and *Illinois Geol. Survey Cir. 106*, pp. 7–11.

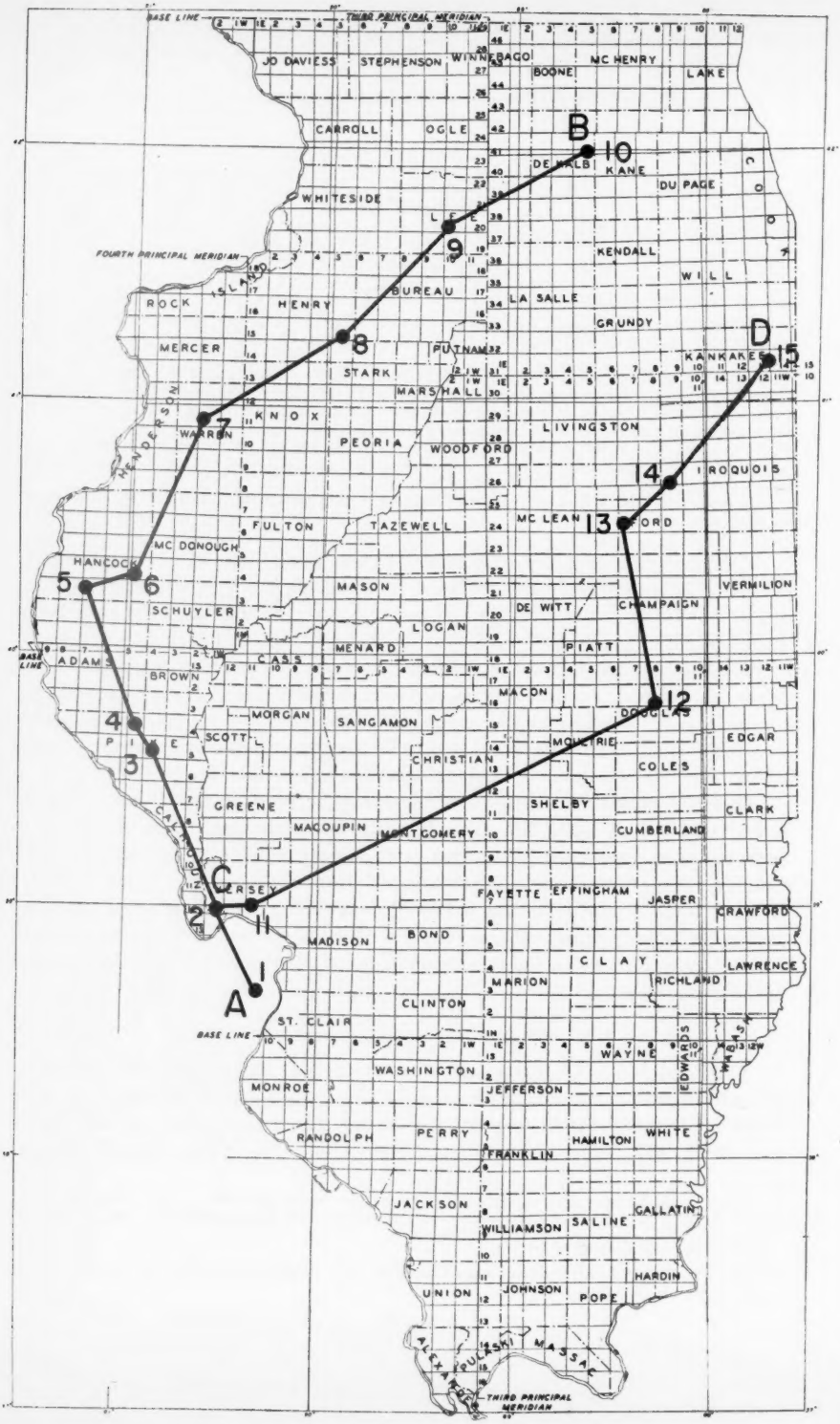

FIG. 1.—Locations of geologic cross sections *AB* and *CD*.

rate in the subsurface from the Mt. Simon, which is white and somewhat finer in texture. There are here and there thin beds of red, greenish gray, and dark gray shale in the Fond du Lac (?). In the wells of northern Illinois that reach or approach the basement granite, 70–440 feet of arkosic sandstone is present in the basal Fond du Lac (?). The Lamotte sandstone of Missouri is equivalent to one or both of these sandstones, and the name Lamotte is commonly applied to the basal sand in near-by Illinois. At the location of well 4 in Pike County (Fig. 1), most of the 445 feet of sandstone overlying the basement rock consists of hematite-coated, recrystallized sand that grades downward to a basal 65 feet of quartz-pebble conglomerate.

The most striking feature of the two geologic cross sections (Figs. 2 and 3) is the great northeastward thickening of the Lamotte-Mt. Simon-Fond du Lac (?) sandstones. These are shown in Figure 4 to increase from 270 feet at St. Louis to 2,255 feet at Momence, Illinois (well 15), where the top of the basement rock was not reached after drilling had penetrated 305 feet of arkosic sandstone. It seems probable that drilling stopped not far above. In northern Wisconsin, 22,000 feet of red clastic, assumably sediment of the same age as the the Fond du Lac, are reported. As the thickening in Illinois appears to increase away from the Ozark area, there is evidence of some influence of the Wisconsin upland in the vicinity of the two northernmost wells shown on the map, where the thickness increases southeastward from 1,600 to 2,125 feet.

A second prominent feature of cross section *AB* is the granite hill at well 3 which rises about 750 feet above the quartzite basement rock at well 4. There is no Mt. Simon-Fond du Lac (?) sandstone at well 3, suggesting that the granite was an island in the sea depositing these sediments. Probably the basement surface everywhere was somewhat uneven, similar to that which may be seen in the exposures of igneous rock under sedimentary beds in the St. Francois Mountains of southeastern Missouri.

EAU CLAIRE FORMATION

The Eau Claire formation consists of sedimentary rocks of a wide variety, including dolomite, limestone, shale, siltstone, and sandstone. They grade laterally in short distances from one to another so that in no two wells are they alike. Most of the rocks are glauconitic, and fragments of linguloid brachiopods and trilobites are common. The siltstones are commonly pink, buff, and green, and contain very fine white to reddish brown mica. The dolomites are generally brown and more or less sandy. The sandstones are commonly dolomitic and fine- to very fine-grained. The shales are green, gray, and dark reddish gray to red, with varying quantities of silt, mica, and sand.

In northeastern Illinois as far west as well 9 on the index map (Fig. 1) the formation can be divided into two parts: the lower half contains considerable dolomite that grades downward and laterally to siltstone and sandstone, and the upper half consists principally of red and green shale interbedded with sandstone,

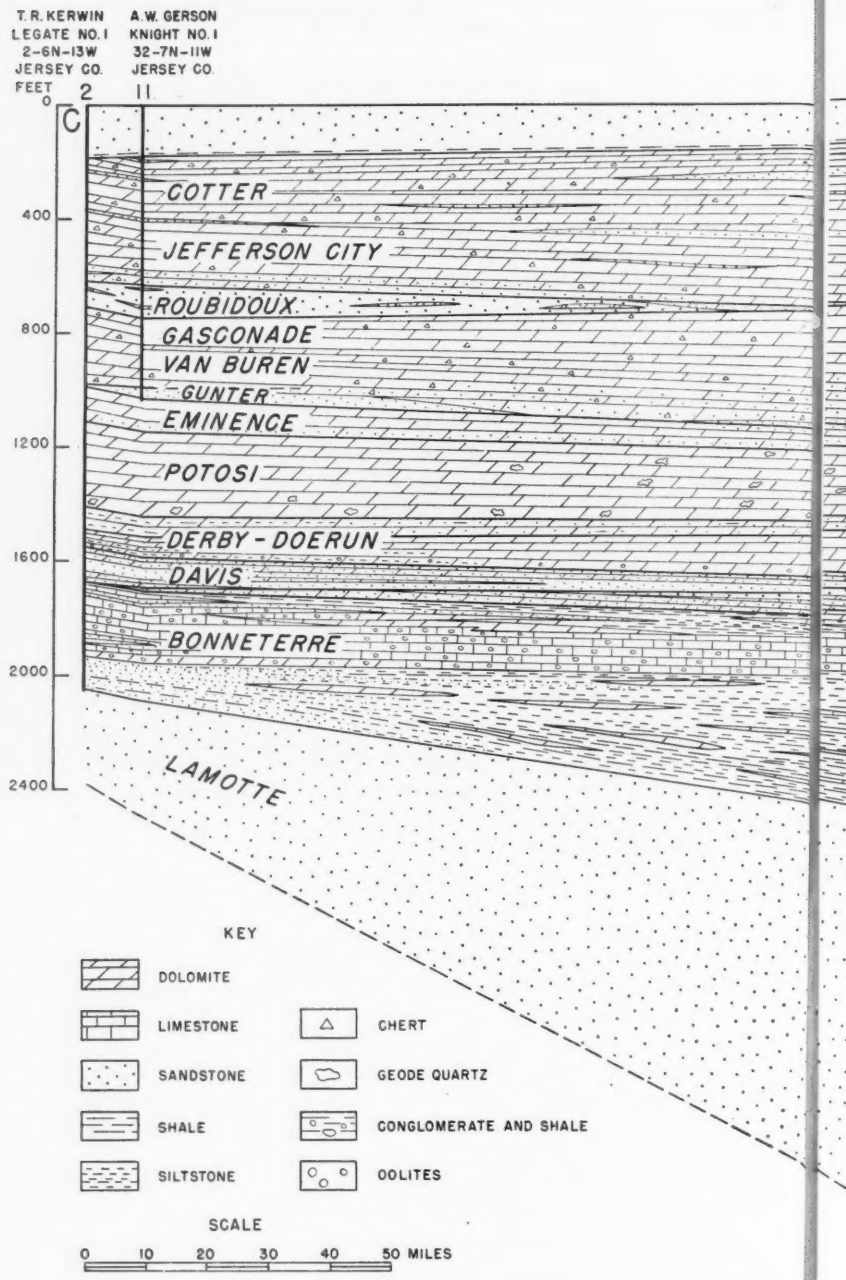

FIG. 2.—Geologic cross section *AB*.

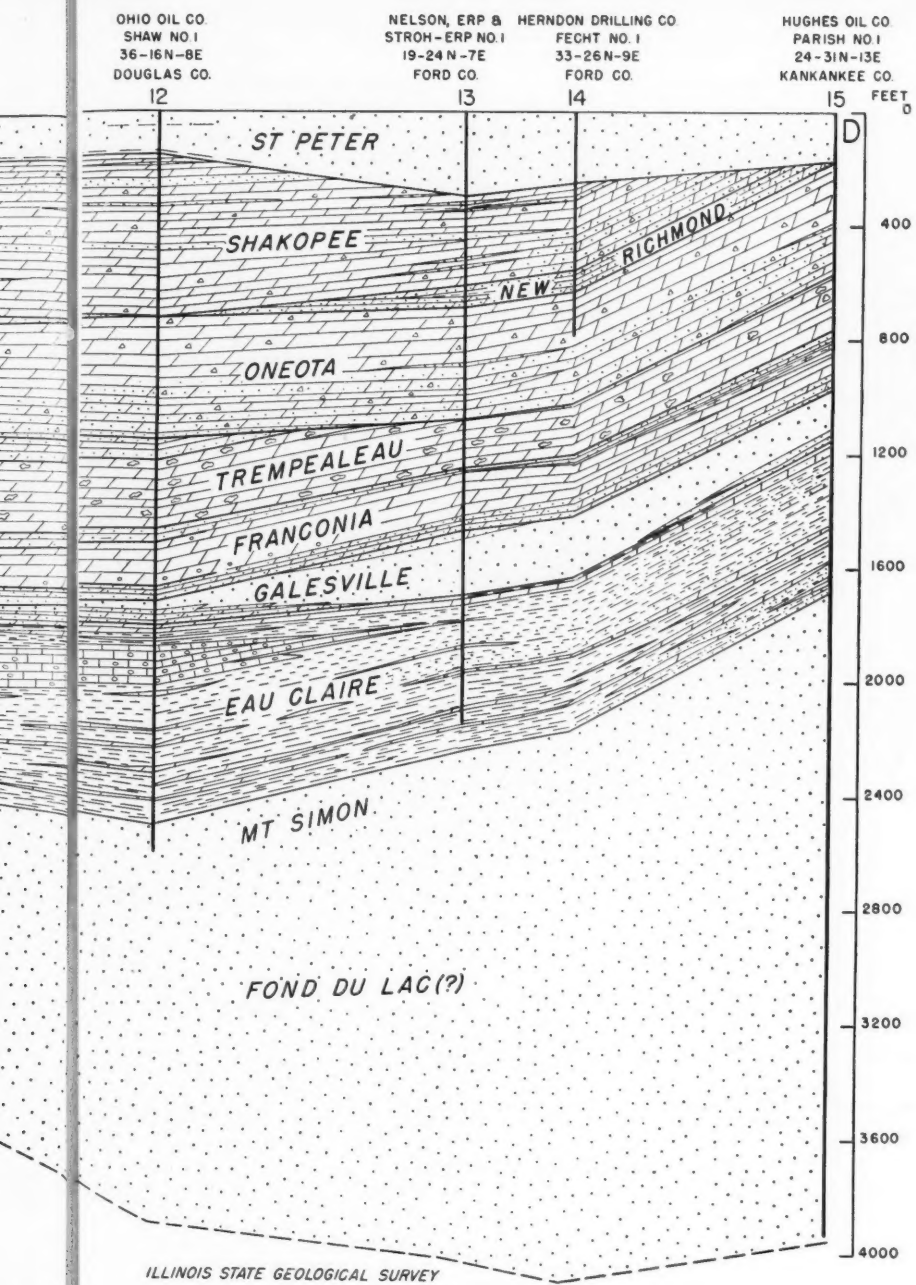

FIG. 2. (*Continued*)

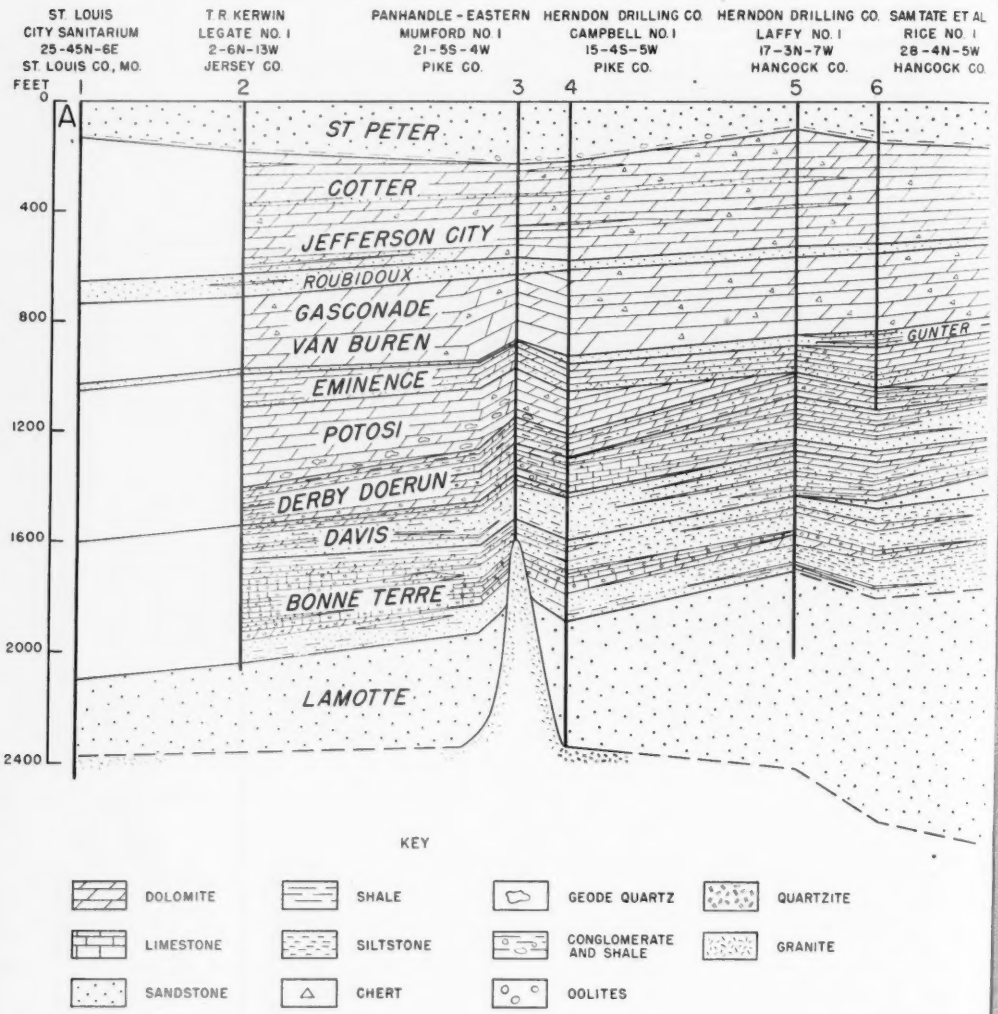

FIG. 3.—Geologic cross section *CD*.

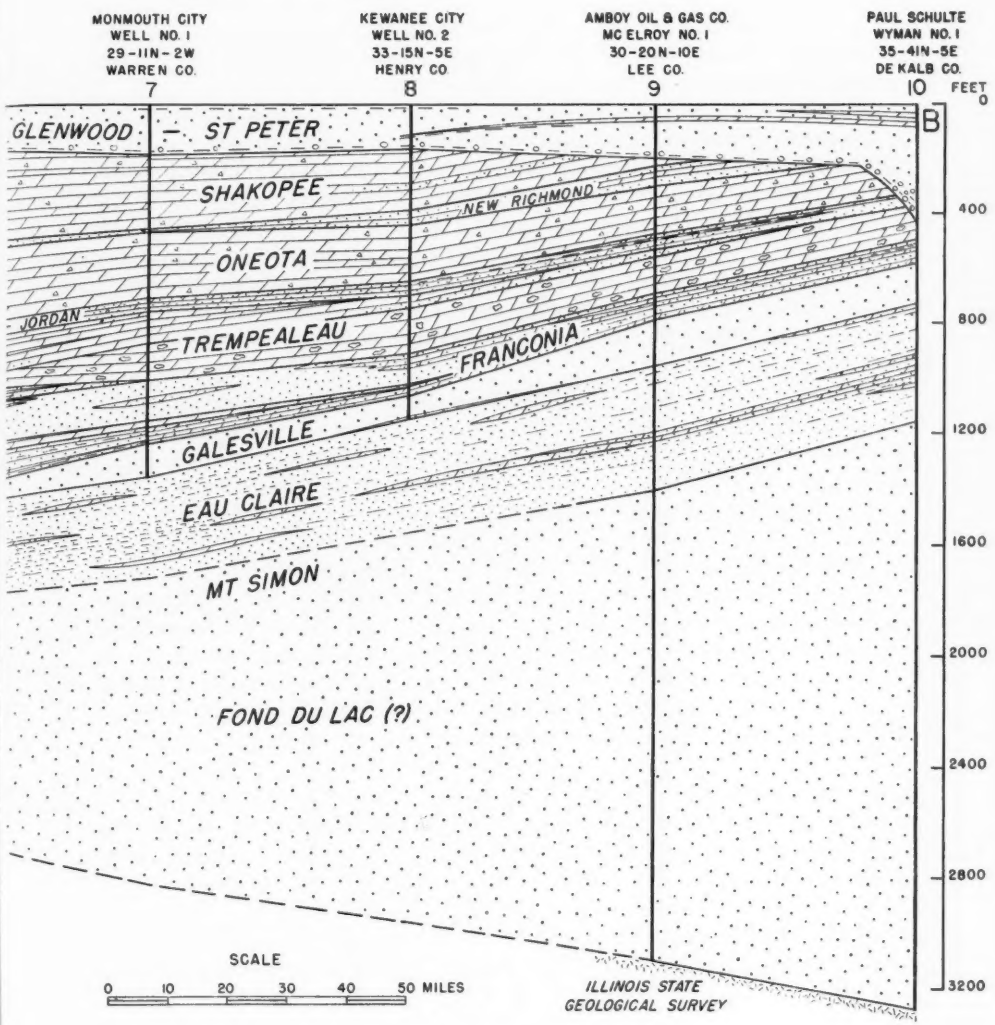

FIG. 3 (*Continued*)

siltstone, and sandy dolomite. Locally, a water-bearing sandstone is present in the base of the upper half. In north-central and northwestern Illinois as far as Rock Island (northwest of well 8) the Eau Claire consists mostly of sandstone, but it contains scattered thin beds of shale and some dolomite, especially near the middle.

Southward from Rock Island no data are available until well 5 is reached, but it is apparent that the dominant sandstone gives way to siltstone and that lenses of dolomite and some limestone become increasingly abundant. Still farther south the limestone and dolomite increase until at well 2 they occupy almost all of the upper two-thirds of the section, the lowest third consisting of very fine-grained sandstone.

Cross section *CD* shows the limestone extending eastward as far as east-central Illinois but disappearing northward from that area. The two parts of the Eau Claire in northeastern Illinois change southward and southwestward. The lower

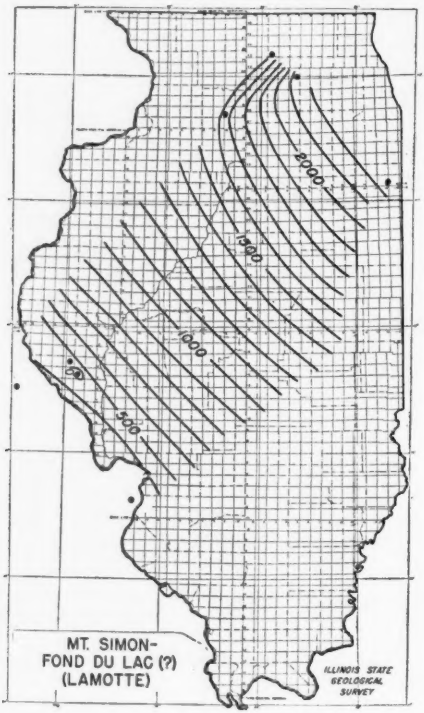

FIG. 4.—Isopach map of Mt. Simon-Fond du Lac (?) (Lamotte) sandstone.

dolomitic half contains increasing proportions of red and green shales, then decreasing shale and increasing sand content until it appears to grade into the sandstone of the lowest third of well 2. However, the upper half (which is more shaly in the north) appears to grade laterally into siltstone with dolomite lenses and finally becomes the limestone and dolomite in the upper two-thirds of the Eau Claire in well 2.

All Eau Claire rocks excepting the oölitic limestones are characterized by very fine glauconite. The sandstones are generally very fine-grained, dolomitic, gray, green, and brown. Most of them are compact and some grade to quartzite, although there are some lenses of incoherent very fine- to medium-grained sand. The lowest sandstone of the Eau Claire in most of northern and western Illinois is incoherent and somewhat coarser than the average, consisting of medium and coarse grains that have on their surfaces a black powder of extremely finely crystalline pyrite which gives the grains a sooty appearance. *Lingula* fragments are common in this zone.

The limestones are of two types. One type is pure, non-glauconitic, consisting of a light grayish brown matrix containing scattered to more numerous chocolate-brown medium to coarse oölites. Most of the thick sections of limestone, and some thin lenses, especially near the top of the Eau Claire, consist of this type. The other type is light gray, light green, light buff to white, very fine-grained, containing varying quantities of very fine sand and glauconite. This type appears mostly as minor lenses in the midst of siltstone. The dolomites of the Eau Claire are grayish brown and very fine-grained. Some contain silt grading to very fine sand; others are pure. The latter dolomites commonly appear to be replacements of oölitic limestone, the oölites having been replaced by coarsely crystalline translucent dolomite in the growth of which the concentric structure has been destroyed but the outer spherical shape has been retained.

The Eau Claire probably is the Bonneterre formation in Missouri where it consists largely of dolomite.

The island of granite at the location of well 3 appears not to have materially affected the characters of the Eau Claire sediments excepting, possibly, to cause the presence of hematite on the surfaces of some sand grains in the upper Eau Claire sandstones. The rock that overlaps directly onto the granite consists of sandy dolomite typical of the upper part of the formation in this region.

The Eau Claire thickens eastward from the Ozark region and southeastward from the Wisconsin region, from less than 300 feet on the borders to more than 650 feet in the southeast (Fig. 5). In the Ste. Genevieve area of Missouri, 20 miles west of the Mississippi River at T. 6 S., R. 7 W., Randolph County, Stuart Weller[4] reported 390 feet of Bonneterre. In Stoddard County, about 40 miles west-

[4] Stuart Weller, "Geology of Ste. Genevieve County, Missouri," *Missouri Bur. Geol. and Mines*, 2d ser., Vol. 22 (1928), p. 39.

southwest of the southern tip of Illinois, a well is reported to have penetrated 1,272 feet of Bonneterre.[5] A well in eastern Indiana, almost directly east of well 12 (Fig. 1), is reported to have penetrated only 600 feet of Eau Claire.[6] From these data it appears that there may be a trough of maximum thickness of the Eau Claire somewhere east of well 12 and extending northeast-southwest through the Stoddard County well.

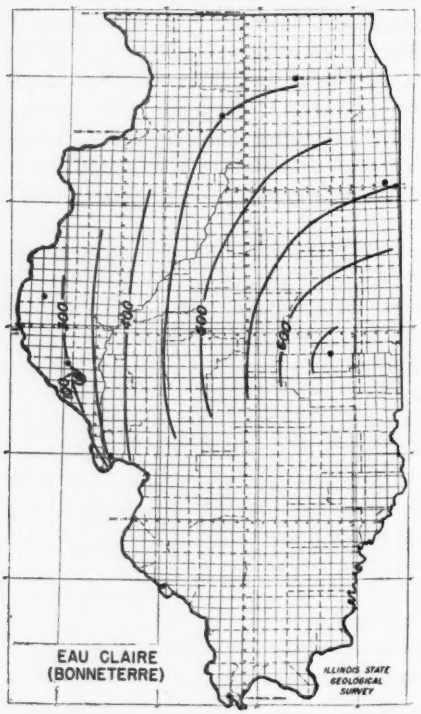

FIG. 5.—Isopach map of Eau Claire (Bonneterre) formation.

GALESVILLE SANDSTONE

The Galesville sandstone is essentially white incoherent sandstone similar to the St. Peter sandstone. In northern Illinois it contains lenses or parts, especially in the upper half, that are cemented with brownish yellow to honey-colored dolomite. The non-dolomitic parts are porous, permitting enormous yields of softer

[5] Log of M. H. Marr *et al.*, C. Barnett 1, center, SW. ¼, SW. ¼, Sec. 3, T. 25 N., R. 11 E., Stoddard County, Missouri, prepared by Missouri Geological Survey and Water Resources.

[6] Log of Ohio Oil Company's May 1, Sec. 12, T. 16 N., R. 11 E., Henry County, Indiana, reported by Ohio Oil Company.

and more potable water than the waters from formations either above or below the Galesville, a peculiarity that may be due to the original nature of the water or possibly to the zeolitic effect of the glauconite in sediments both above and below. There is no glauconite in the Galesville. In well 12 (Fig. 1) the dolomite content is greatly increased so that two-thirds of the formation consists of pale to dark brown sandy dolomite. Here and there brown oölites occur in the dolomite and sandstone from this well.

The thickness of the Galesville formation is generally 150–200 feet in northern Illinois as far south as the 200-foot isopach in Figure 6. Southward, however, it thins and in a short distance disappears.

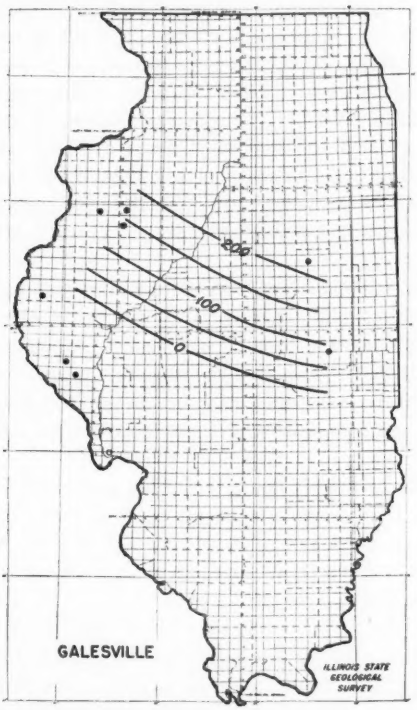

FIG. 6.—Isopach map of Galesville sandstone.

Raasch[7] postulates that the Galesville was deposited in a broad and very shallow basin, connected by rather restricted channels with the sea, into which there was so copious a flow of fresh water that normal marine organisms could not thrive, glauconite could not be formed, and argillaceous material could not be

[7] Gilbert O. Raasch, "Stratigraphy of the Cambrian System of the Upper Mississippi Valley," *Kansas Geol. Soc. 9th Ann. Field Conf. Guide Book* (1935), p. 307.

flocculated. The first southward appearance of oölitic limestone in the Eau Claire in wells 5 and 12, the greatly increased dolomite content in the Galesville in well 12, the pronounced southward thinning of the Galesville, and the appearance of a few oölites in the Galesville in well 12, all indicate that a line of change of sediments, or a barrier, occurs probably not far north of wells 5 and 12.

FRANCONIA FORMATION

The Franconia formation is in many ways similar to the Eau Claire, having a similar variety of sandstones, siltstones, shales, dolomites, and limestones. In the northern part of the line of cross section *AB* as far south as well 7 it consists mostly of very fine-grained sandstones grading to dolomites having shades of green, pink, brown, and gray, all but the basal part of which contains very fine-grained glauconite. In areas near-by but not represented in the cross section, gray, green, red, and brown shales are found. South of well 7 the Franconia expands greatly and grades to considerable proportions of sandy dolomite and some limestone. In its entirety the Franconia may be divided into five parts: (1) basal coarse-grained glauconitic sandstone; (2) lower sandstone to sandy dolomite; (3) middle dolomite to limestone; (4) upper sandstone to sandy dolomite toward the north; (5) upper silty and partly sandy dolomite with brown shale partings toward the south.

The basal sandstone consists of a mixture of medium to coarse glauconitic sand cemented with buff dolomite similar in color to the dolomite in the underlying Galesville sandstone. The zone is commonly less than 5 feet thick but in places is as much as 15 feet thick. This is the Ironton member of the Franconia in Wisconsin, considered to be the basal conglomerate of the formation. It serves to identify the contact of Eau Claire and Franconia where no Galesville separates them.

The lower sandstone to sandy dolomite is very fine-grained and contains much very fine glauconite. It is variable, with siltstones and shale partings of various colors. It is only 30 feet thick at the location of well 8 but expands southward to the maximum of 170 feet in well 4. This may be equivalent to the Davis of Missouri as interpreted in Figure 2, or it may be only the lower part of that formation.

The middle dolomite to limestone member at well 4 consists of 125 feet of white, light gray, and brown lithographic to very fine-grained limestone with partings of dark brown shale and scattered oölites. Southward in a distance of 9 miles to well 3 the limestone gives way to 115 feet of pure, white to brown, partly oölitic dolomite without shale partings. The structure of the oölites indicates that, like the Eau Claire, the rock was originally limestone but was replaced by dolomite. Farther south to well 2 the pure dolomite grades to 60 feet of brownish gray silty dolomite containing a few oölites. Northward from well 4 the zone is represented by a decreasing thickness of amber-colored pure dolomite that can be traced as far as well 8.

The upper sandstone to sandy dolomite is similar to the lower sandstone to

sandy dolomite. It increases in thickness southward, reaching the maximum of 150 feet in well 5 but farther southward it disappears abruptly, with no indication of it in well 4. Whether it grades laterally into the limestone, as interpreted in the cross section (Fig. 2), or overlaps the limestone and was subsequently removed by erosion is conjectural.

The top zone of the Franconia is light brown silty and partly sandy very fine-grained dolomite that contains scattered very fine flakes of glauconite and is characterized by numerous thin partings of dark brown shale. Its thickness ranges between 70 and 90 feet. It extends as far north as well 6.

Correlation of the upper parts of the Franconia with formations recognized in Missouri is difficult. There is little doubt that the basal coarsely glauconitic sandstone and the lower sand and dolomite zone are in the Davis formation. The top dolomite with brown shale partings appears to fit the description of the Doerun argillaceous dolomite.[8] The middle dolomite-limestone would thus be correlated with the Derby. This conclusion is somewhat questionable, however, because the Davis formation in Missouri is described as characterized by the presence of limestones, some of them oölitic, one bed in particular being described as a marble bed suggestive of the white lithographic limestone in well 4, whereas the Derby is described as dolomite only.[9] Further studies will be needed on this problem.

The thickness of the Franconia in northern Illinois ranges from less than 100 feet to 150 feet. It increases southward (Fig. 7) to the known maximum of 440 feet at well 5 on the west, and 265 feet at well 12 on the east. These thicknesses occur in the general east-west belt across central Illinois where various Cambrian strata are considerably affected by structural warping and facies changes. It is not certainly known that the Franconia thins southward from well 12, as suggested.

TREMPEALEAU FORMATION

The Trempealeau formation consists of two dolomites which are thought to represent in Missouri the Potosi formation below and the Eminence formation above.

The Potosi dolomite is pale brown, buff, pink, and light gray, very finely to finely crystalline. It contains variable amounts of geode quartz and scattered flakes of glauconite. The formation is absent in wells 5 and 6, but reaches a thickness of 290 feet in well 2. It is thinnest across central Illinois, appearing to have been removed by erosion along the crest of a post-Potosi anticline that extends east and west, plunging east (Figs. 2 and 8).

The Eminence dolomite is white to light buff, finely to medium crystalline, and contains some very finely dolomoldic white dense chert. It is sandy in some

[8] E. R. Buckley, "Geology of the Disseminated Lead Deposits of St. Francois and Washington Counties," *Missouri Bur. Geol. and Mines*, Vol. 9, Pt. 1 (1908), pp. 47–49.

[9] *Ibid.*, pp. 33–46.

localities, as in the vicinities of wells 3, 5, and 6, but elsewhere it is less sandy, and in some places is practically free of sand. As suggested in Figure 9, it is more than 100 feet thick in a wide area of west-central Illinois, reaching the known maximum of 140 feet in well 6, and thins northeastward, being absent in wells 13 and 15.

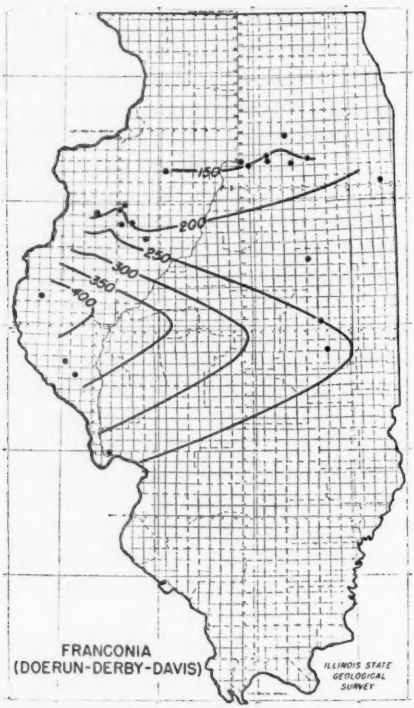

FIG. 7.—Isopach map of Franconia formation (Doerun-Derby-Davis).

GUNTER-JORDAN FORMATIONS

Overlying the Trempealeau formation is a relatively thin zone of sandstone, sandy dolomite, and green and red shales, all of which are variable from well to well. The sandstone is very fine- to coarse-grained, in some places well sorted but more commonly poorly sorted. Some grains are angular due to secondary crystalline quartz on the surfaces of previously rounded grains. Where the sand is poorly sorted the formation ordinarily contains loose siliceous oölites of the size of medium to coarse sand. The dolomites are white, light and medium gray, pink, and light brown, and contain oölitic chert and some sand. The shales are relatively few but their clear colors of bluish green and red are distinctive. Some sand is present in the shale.

In Missouri this sandstone zone is known as the Gunter member of the Ordovician Van Buren formation, and is described as basal sand grading upward into dolomite. In northern Illinois the sandy beds at this horizon have been known as the Jordan formation which is considered Upper Cambrian in age. No

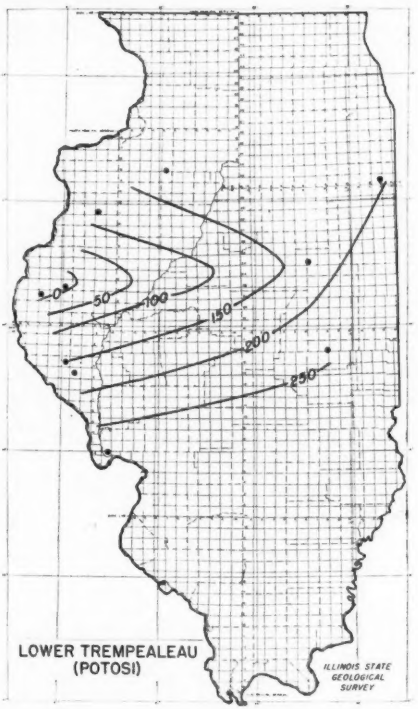

FIG. 8.—Isopach map of lower Trempealeau strata (Potosi).

satisfactory way has been found for separating the zone in the subsurface into two sandy zones, the one Cambrian and the other Ordovician, nor is it possible to determine that there is a single zone limited to either Ordovician or Cambrian in the area of this report. Therefore the terms are used together to indicate a single sandy zone. It is evident that part of the Gunter-Jordan in Illinois consists of basal Ordovician sandy beds that grade upward into the Oneota dolomite. As shown in cross section *CD* the basal Oneota contains sand as much as 200 feet thick in east-central Illinois.

No isopach map of the Gunter-Jordan is attempted here, but for purposes of drawing the isopach map of the overlying Oneota formation the zone is considered to be 10–40 feet thick, locally 50 feet, as indicated in the cross sections.

ONEOTA DOLOMITE

The Oneota dolomite is white to light gray, very finely to coarsely crystalline, somewhat vesicular, with partly oölitic, white to gray, granular to dense chert. The formation is generally not very sandy but does contain scattered "floating" sand grains and becomes sandy toward the base where it grades into the Gunter-Jordan sandstone. Sand extends upward as far as the middle of the formation in

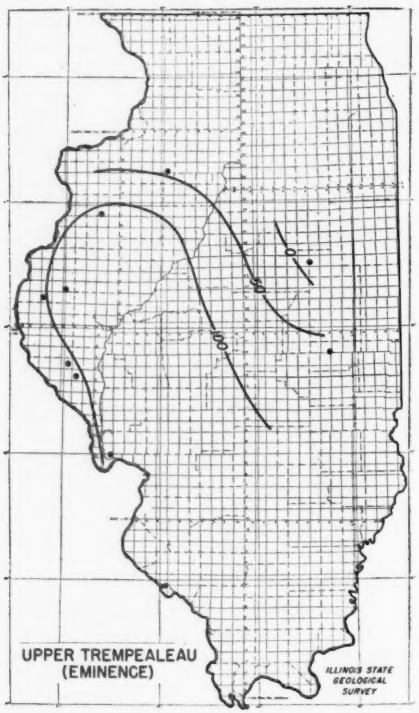

FIG. 9.—Isopach map of upper Trempealeau strata (Eminence).

east-central Illinois. The Oneota is the Van Buren (below) and the Gasconade (above) of the Missouri geologic column.

The thickness of the Oneota (Fig. 10) increases generally southeastward from the Wisconsin upland and eastward and northeastward from the Ozark region, in a manner similar to that of the Eau Claire and Eminence formations, from 200 feet to the known maximum of 424 feet.

At well 3 local uplift and erosion of the Pittsfield anticline removed the top of the Oneota before the New Richmond sandstone was deposited.

NEW RICHMOND SANDSTONE

The New Richmond sandstone in its area of maximum development in La-Salle County is much like the St. Peter sandstone in appearance, being composed of white fine- to coarse-grained friable quartz sand. However, it differs in containing some siliceous oölites and in grading laterally to dolomitic sandstone and

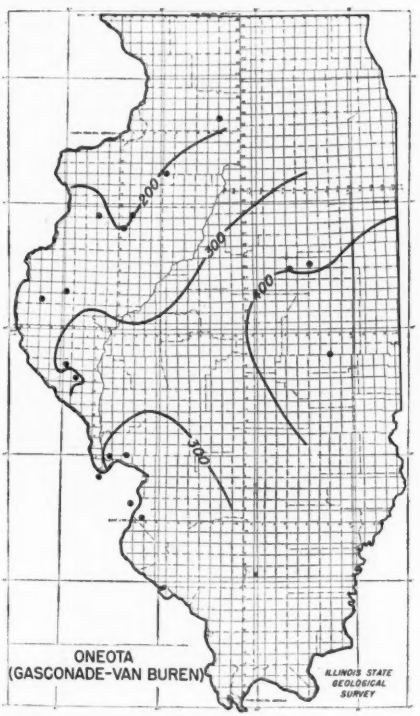

FIG. 10.—Isopach map of Oneota formation (Gasconade-Van Buren).

some dolomite. Red, blue, and gray shales occur in places in the lower part. Secondary clear crystalline quartz added to the surfaces of the rounded grains is not uncommon.

The New Richmond is equivalent to the Roubidoux sandstone and dolomite formation of Missouri but probably it does not represent all that is designated as Roubidoux. The sandstone grades upward into the Shakopee like the gradation of Gunter-Jordan into the Oneota. In Illinois the New Richmond is considered as only the dominantly sandstone part but the Roubidoux in Missouri is considered to extend upward into the dolomite part.

The greatest known thickness of 190 feet of the New Richmond in Illinois was logged in a well in Starved Rock State Park,[10] LaSalle County (Fig. 11). Logs of numerous other wells on the east, north, and west show thinning in those directions. Scattered wells on the south suggest that the thickest part of the

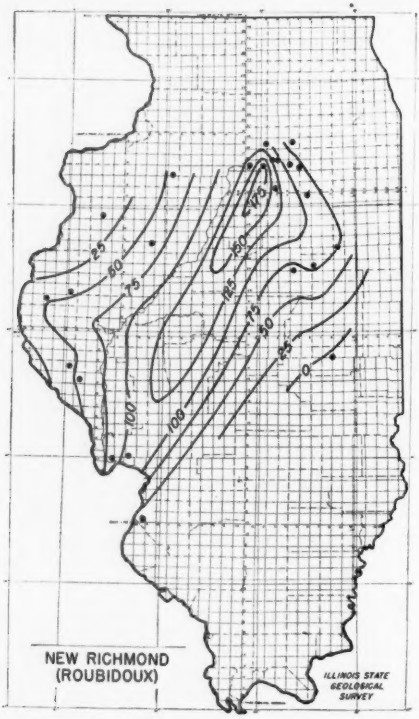

FIG. 11.—Isopach map of New Richmond sandstone (Roubidoux).

sandstone extends southwestward to a point near Alton where it is slightly more than 100 feet thick. The formation wedges out eastward in Douglas County and thins westward to 25 feet along the western border of the state.

SHAKOPEE DOLOMITE

The Shakopee formation consists mostly of light to medium gray very fine- to fine-grained dolomite. It contains chert that is dull to dense, partly oölitic, similar to that of the Oneota. As indicated in the cross sections (Figs. 2 and 3),

[10] J. Norman Payne, "Geology and Mineral Resources of the Marseilles, Ottawa, and Streator Quadrangles," *Illinois Geol. Survey Bull. 66* (1942), pp. 59, 337.

there are lenses of sandstone in the Shakopee, most of which are local but some of which appear to extend through two or more consecutive wells. Thin red, gray, and green shale lenses are present. The Shakopee is correlated with the Jefferson City and Cotter dolomites of Missouri.

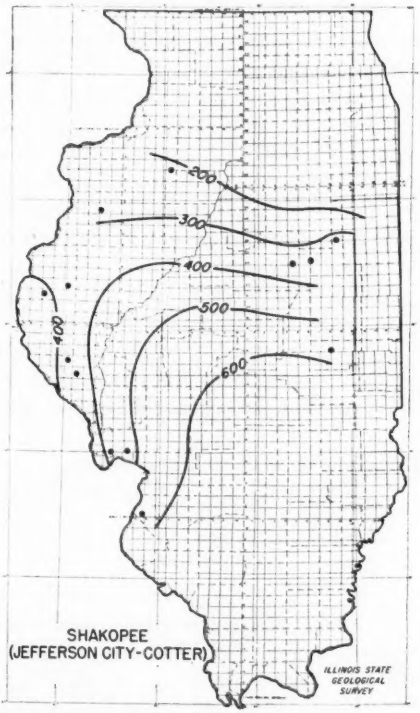

FIG. 12.—Isopach map of Shakopee formation (Jefferson City-Cotter).

An erosional unconformity separates the Shakopee from the St. Peter sandstone. The thicknesses of the Shakopee in various wells are irregular because the pre-St. Peter surface was a youthful topography. Maps of the areal geology of the pre-St. Peter surface and the thickness of the St. Peter sandstone[11] indicate maximum relief of 500 feet in northeastern Illinois. Although the data used in drawing the isopach map of the Shakopee formation (Fig. 12) are insufficient for detail, the general picture of the thickening of the Shakopee southward from the Wisconsin upland and eastward from the Ozarks to approximately 600 feet is essentially correct.

In northern Illinois many wells have encountered crevices and cavities in the

[11] Marvin P. Meyer, "Pre-St. Peter Areal Geology of Northern Illinois," unpublished manuscript, *Illinois State Geol. Survey* (1947).

Shakopee and older formations directly underlying the erosion surface covered by the St. Peter sandstone. Such openings are scarcer on the south because there was a decreasing amount of uplift southward previous to St. Peter deposition.

GLENWOOD-ST. PETER SANDSTONE

The St. Peter sandstone is typically very fine- to medium-grained incoherent white sandstone. It contains no limestone or dolomite, but thin green shales are locally present. At its base is a varying thickness of conglomerate composed of chert pebbles in a matrix of red, green, and gray sandy to smooth shale. The Glenwood is a relatively thin formation overlying the St. Peter sandstone. It contains sands similar to the St. Peter, also argillaceous dolomite and sandy green shale. St. Peter and Glenwood are generally considered together for studies of structure and stratigraphic thicknesses because it is difficult to separate them either in the subsurface or in the outcrop.

In the southern two-thirds of the state the thickness of the Glenwood-St. Peter sandstones in the wells ranges between 100 and 300 feet, averaging 180 feet. Because the variation is irregular an isopach map of the two formations would not be significant. The sandstone filled the valleys in the pre-St. Peter surface and spread out as a blanket 180 feet thick above the general level of the pre-St. Peter surface.

Because of the scarcity of data the rather even basal surface of the St. Peter as drawn in Figures 2 and 3 should not be considered as a true picture of the irregular contact.

STRUCTURE

The structure map of the top of the Glenwood-St. Peter sandstones (Fig. 13) shows the general structure of the Illinois basin in 1,000-foot contours, descending southward from 1,000 to more than 6,000 feet below sea-level. The deepest well to reach the St. Peter is the Pure Oil Company's Stella Billington No. 3 in Wayne County where the St. Peter is 6,600 feet below sea-level at the total depth of 7,046 feet. The concentration of dissolved mineral matter in water from the St. Peter sandstone is also shown in Figure 13 by isocons, or lines of equal concentration. They indicate increasing concentration with depth in the basin.

A generalized structure map of the surface of the basement granites and metamorphic rocks is given in Figure 14. Only 6 wells used in preparation of this map reached the basement rocks but enough wells on the periphery of the basin were deep enough to reveal the trend of thickening of formations and thus to furnish a basis for estimating depth to the basement rocks in the basin. The map shows eastward slopes of the basement surface from the Ozark region twice as steep as the southward slopes from Wisconsin, and the surface appears to have maximum depth of more than 11,000 feet below sea-level in southeastern Illinois. The surface is uneven and it is probable that granite hills similar to those exposed in the St. Francois Mountains of southeastern Missouri and encountered at well 3

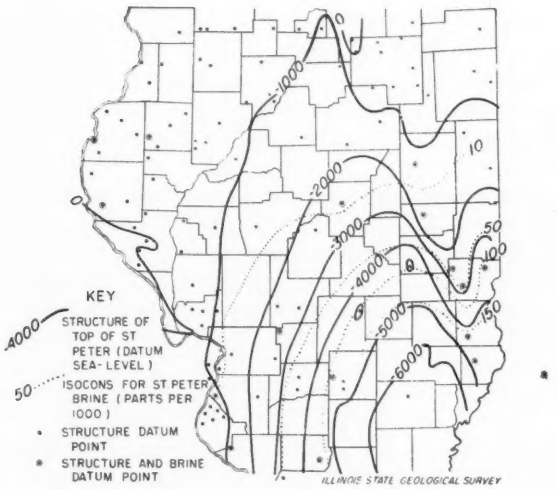

FIG. 13.—Structure of top of St. Peter formation and isocons for St. Peter brine.

are numerous. The top of granite in well 3 is 1,401 feet below sea-level and in well 4 it is 2,484 feet, a difference of 1,088 feet. This occurrence of a granite hill under the Pittsfield-Hadley anticline suggests that similar granite hills may be present under other anticlines of the Illinois basin. However, in Figure 14 no attempt is made to locate such granite hills.

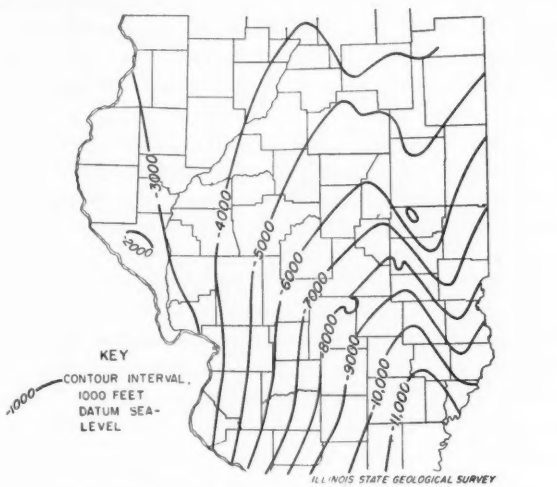

FIG. 14.—Structure of surface of basement complex.

OIL AND GAS POSSIBILITIES OF ST. PETER AND LOWER FORMATIONS

The results of drilling do not indicate favorable prospects for oil in the St. Peter and lower formations in the northern third of Illinois. The other part of the state is largely untested below the St. Peter and therefore is regarded as having oil possibilities in porous zones of the sedimentary rocks from the top of the St. Peter downward.

The St. Peter sandstone itself has been tested and found dry on several prominent structures in the basin area, including Louden, Salem, Mattoon, the La Salle anticlinal belt in Douglas, Clark, Crawford, and Lawrence counties, the Noble[12] anticline, and the DuQuoin anticline. On the Mattoon anticline oil stains were found in a few feet of the Glenwood sandstone directly above the St. Peter sandstone, but no oil was found in the St. Peter or Glenwood in the test wells on the other structures mentioned. In the Pure's Billington deep test in the Cisne pool on the Noble anticline, the St. Peter was found to be tight and quartzitic.

Zones deeper than the Glenwood-St. Peter sandstones that are especially porous are the crevices and cavities in the Shakopee dolomite, the porous New Richmond sandstone in its area of considerable thickness in central Illinois, the crevices and cavities in the Trempealeau dolomite, the Galesville sandstone north of its wedge edge, lenticular parts of the Eau Claire formation, and the Mt. Simon-Fond du Lac (?) sandstone. These strata have been tested in only a few spots and no authenticated showings of oil have been reported in them.

Nearly all of the oil fields of Illinois are included in an area of 12,000 square miles in the south half of the state. Nearly 75 per cent of the total oil has come from Mississippian strata, 20 per cent from Pennsylvanian strata, 4 per cent from Devonian strata, and only 1 per cent from the Silurian and Ordovician together. All of the Ordovician oil is from the "Trenton" in the upper part of the system. There is, thus, a general decrease in oil productivity by systems from the Mississippian down.

This may appear to be due to the fact that the amount of drilling becomes less with increased depth, but actually there may be less oil in the deeper formations. In oil fields with production from several zones widely separated in depth, for example Westfield, Salem, and Louden, production areas are notably smaller for the deeper zones. If this trend toward smaller productive areas continues downward, oil accumulations in the pre-St. Peter Ordovician and in the Cambrian formations on known structures may be small.

It must be recognized that below old unconformities there may be structures that are not reflected in known key horizons. It appears that the only chance of finding such structures in advance of drilling would be by geophysical methods. Also stratigraphic traps may occur in Ordovician and Cambrian rocks as well as in younger systems.

[12] Name proposed by Darsie A. Green in paper presented at the Eastern Interior regional meeting in St. Louis, January 14–15, 1948, for the Clay City anticlinal belt.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2063-2082, 12 FIGS.

HITESVILLE CONSOLIDATED FIELD, UNION COUNTY, KENTUCKY[1]

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Fort Worth, Texas

ABSTRACT

The Hitesville Consolidated field is on a broad irregular anticline trending north and south, 4½ miles north of the Shawneetown-Rough Creek fault system in Union County, Kentucky, at the southern extremity of the Illinois basin. The field was discovered in February, 1943, and now includes approximately 3,500 productive acres. The Chester of the Upper Mississippian produces from the Waltersburg, Tar Springs, upper and lower Cypress, and Aux Vases sands. The Ste. Genevieve of the Lower Mississippian produces from seven separate porous McClosky zones. Sixty-one per cent of the wells produce from the McClosky and 20 per cent from the Cypress. The most outstanding feature of this field is the multiple-zone McClosky production.

LOCATION

The Hitesville Consolidated field is in the northeastern part of Union County in western Kentucky, approximately 12 miles southwest of Henderson, 5 miles east of Uniontown, and 4 miles northeast of Morganfield, centering at the common corner of Quadrangles O-20 and 21 and P-20 and 21 (Fig. 1).

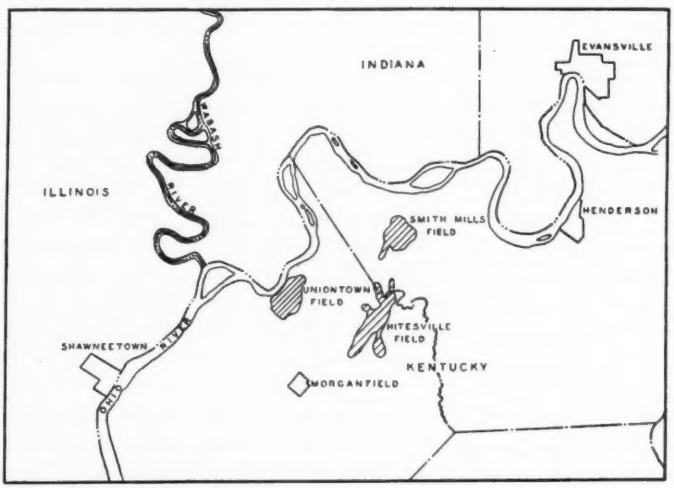

FIG. 1.—Part of Tri-State area showing Hitesville Consolidated field.

[1] Read at the Eastern Interior regional meeting, St. Louis, Missouri, January 15, 1948. Manuscript received, June 14, 1948.

[2] Geologist, Continental Oil Company. Formerly with The Carter Oil Company.

Regional Geology

Union County, Kentucky, is in the southern part of the Illinois basin and is traversed east and west by the Shawneetown-Rough Creek fault system, which in general marks the southern boundary of the productive part of the Illinois basin. The Hitesville Consolidated field is on a rather broad irregular anticline trending approximately north and south and at right angles to the Shawneetown-Rough Creek fault, the south end of the field being 4½ miles north of the fault. West of the Hitesville anticline is a broad shallow syncline bordered on the west by the Uniontown anticline and fault (Fig. 2).

The east side of the Hitesville anticline is bounded by a syncline which is expressed northward by a fault with maximum displacement of 100 feet. East of the syncline a relatively flat area continues 10 miles with only minor subsurface variations, which include a few small pools with less than 30 feet of closure.

North of the Hitesville Consolidated field and on an elongate nose of the Hitesville anticline, approximately 75 feet lower structurally, is the Smith Mills field, with 112 wells producing from the Cypress and McClosky.

The entire area is affected materially by very erratic sand conditions, the sand bodies being present in the form of bars and lenses. The Cypress sand is the nearest approach to a blanket sand though it is erratic, varying in thickness as much as 100 feet.

Discovery

The discovery of the Hitesville Consolidated field has been credited to core-drill, seismograph, and subsurface geological work. The first well drilled in the area was the Hogan *et al.* G. Greenwell No. 1 in Sec. 9, O-20, completed in October, 1939, as a dry hole at 2,675 feet, 122 feet below the top of the Ste. Genevieve. The second well was The Carter Oil Company's E. Spencer No. 1 in Sec. 25, P-20, a dry hole completed through the Ste. Genevieve in July, 1942. The third well, and the first producer, was Miller and Shiarella's Willett No. 1 in Sec. 16, P-21, completed in the McClosky limestone in February, 1943, and initially producing 200 barrels of oil in 24 hours. The second producer was the Hogan *et al.* G. Greenwell No. 1, which was reopened and tested by H. H. Weinert and the Pure Oil Company in June, 1943, and initially produced 318 barrels of oil in 24 hours from the McClosky limestone. The third producer in the area was the Carter's L. Russelburg No. 1 in Sec. 24, P-21, completed in July, 1943, in the Waltersburg sand and initially producing 182 barrels of oil in 24 hours. These three producers are credited as discovery wells of the Utley, St. Vincent, and Hitesville pools, respectively, which have been proved by drilling to be a continuous productive area. A fourth producing area in Sec. 7, P-21, discovered by the Ashland's Verona Coal Company "A" No. 1, completed in May, 1945, was originally called the Waverly pool. These four pools are now known as Hitesville Consolidated, which now includes approximately 3,500 productive acres.

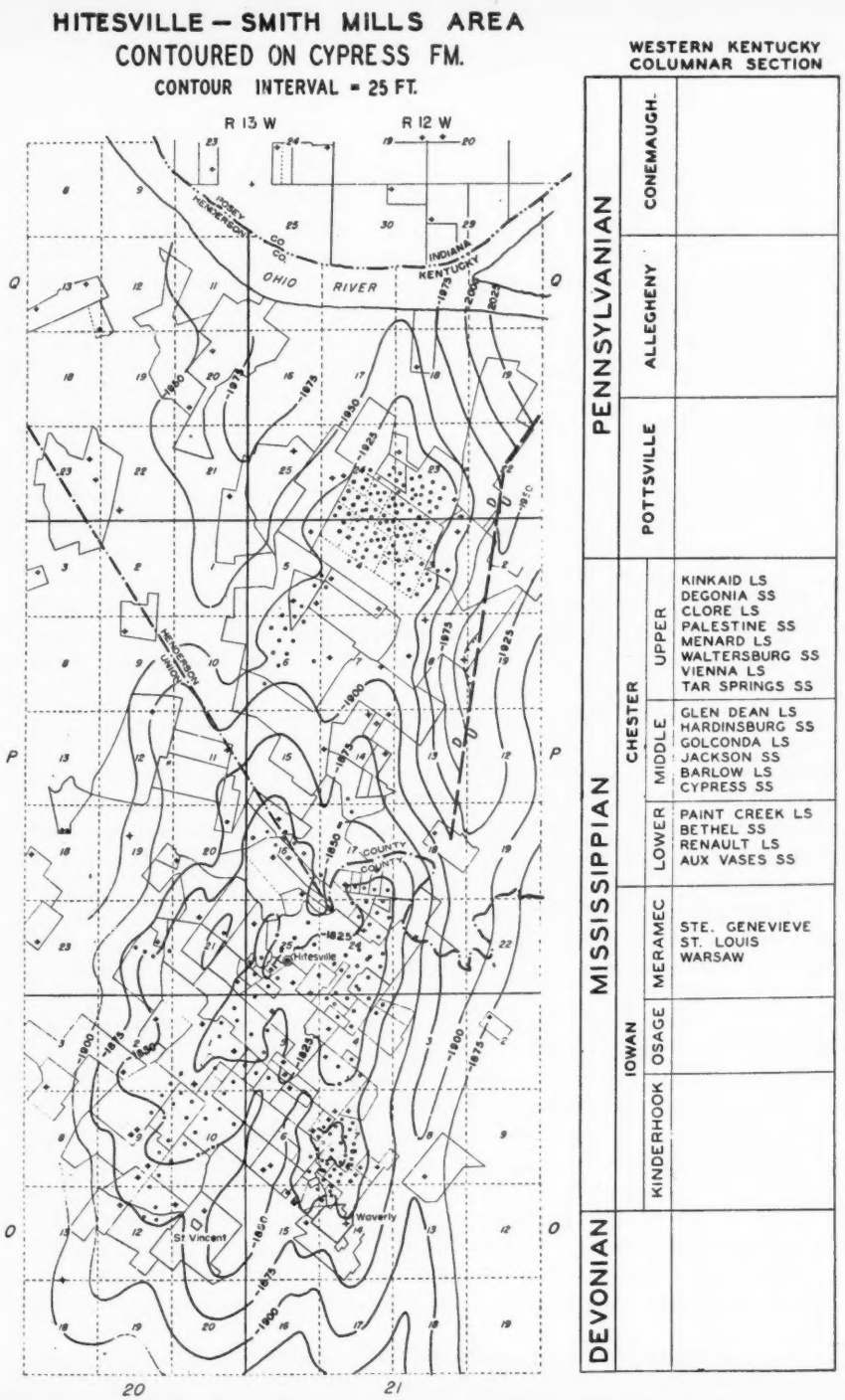

FIG. 2.—Regional map of Hitesville-Smith Mills area contoured on Cypress formation, 25-foot interval.

Importance

The Hitesville Consolidated field is on the largest known anticline in western Kentucky as far as areal extent is concerned, and of further importance is the fact that each Chester sand present, excepting the Hardinsburg sand, is productive at one place or another in the field. However, the dominant feature of the field is the multiple-zone production of the Ste. Genevieve. In the Ste. Genevieve seven separate zones are recognizable in most parts of the field. Eight wells in the field are each producing from three zones, and 35 are producing from two zones.

As a McClosky field, Hitesville Consolidated ranks first in area and reserves in western Kentucky and southwestern Indiana, and about tenth in the entire Illinois basin area.

Development

The development of the field has been comparatively slow, though it was accelerated when the St. Vincent and Waverly parts of the field were being drilled. The north-south length of the field is slightly more than 5 miles, and the width approximately 2 miles. The spacing pattern is rather erratic, because of the irregular shapes of the leases and erratic occurrence of productive Chester sand bodies. The average well density is approximately one well to 25 acres, with attempts at 10-acre spacing for the sand wells and 20- and 40-acre spacing for the limestone wells.

The Hitesville anticline has 75–110 feet of structural closure on the Mississippian markers (Figs. 3, 4, and 5). The 75-foot minimum is present on the Cypress formation and the 110-foot maximum is present on both the Waltersburg formation and the top of the Ste. Genevieve. Two apparent north-south ridges parallel the structure, slightly converging toward the north, and the most prolific production is along these ridges; however, other minor irregularities are present over the comparatively flat surface of the anticline.

The principal accumulation of oil on the structure is in the McClosky, the Cypress sand is second, the Waltersburg sand third, the Tar Springs sand fourth, the Aux Vases sand fifth, and a Pennsylvanian sand is sixth and of very little importance (Fig. 6).

The productive sand bodies may be classified into two groups: (1) those with a large area and a definite water drive and water level, and (2) those isolated sand lenses with only a gas-expansion type of drive with no water associated with the oil. The limestone reservoirs may be similarly grouped.

On November 1, 1947, the Hitesville Consolidated field had produced 3,966,000 barrels of oil from 146 wells, and in October it had a daily average production of 2,276 barrels of oil. The average accumulated production per well as of the first of November is 27,160 barrels. The highest known production of a single well in the field is 103,494 barrels of oil from the Carter's Culver Heirs No. 3 in Sec. 24, P-21, which was completed in December, 1943, and is currently producing 52 barrels of oil per day from the McClosky "D" zone. The well which in

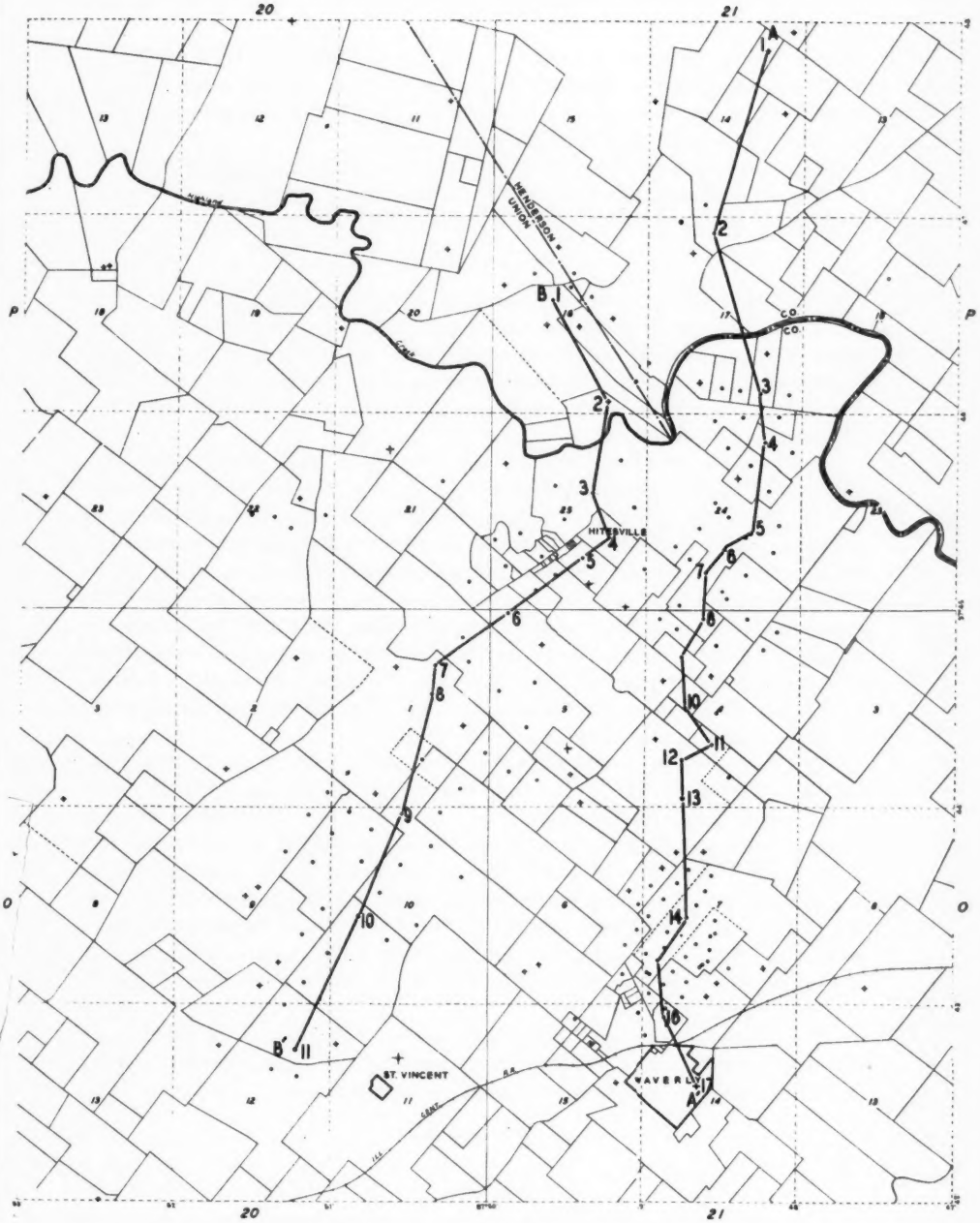

FIG. 3.—Map of Hitesville Consolidated field showing location of cross sections.

the near future will rank as number one is the Carter's J. C. Hancock No. 2, which was completed in February, 1946, has produced 74,647 barrels of oil to December 1, 1947, and currently produces a daily average of 105 barrels of oil from the "A" and "B" McClosky zones.

Many wells in the field have produced in excess of 60,000 barrels of oil.

The estimated ultimate recovery of the field from all producing zones is approximately 6,500,000 barrels of oil (A. P. I. estimate, January, 1947).

Pennsylvanian

The first important marker encountered in the Hitesville area is the Providence limestone, which is 200–300 feet in depth and is 2–10 feet thick. The Kentucky No. 11 coal underlies the limestone. This coal varies from 1 to 6 feet in thickness and is mineable in the area. Approximately 110 feet below the No. 11 coal is the Kentucky No. 9 coal, which also varies from 1 to 6 feet in thickness and is classified as mineable.

Nearly all of the Pennsylvanian shales are highly micaceous and many are highly sideritic, the siderite commonly occurring in massive form or in small pellets. The shales also contain varying amounts of carbonaceous material and grade in color from light gray to black. There are a few thin gray-green waxy shale sections, but this type of shale can not be classified as characteristic of the Pennsylvanian section. Another characteristic of the Pennsylvanian shales is the somewhat higher resistivity as shown on an electrical log in comparison with the underlying Chester shales. The Pennsylvanian-Chester contact can be identified in this way where the contact occurs in shale. The change in resistivity is probably caused by the change in the amount of mica from the Pennsylvanian to the Chester shales. Chester shales contain very little mica.

The Pennsylvanian sands are not economically important in the Hitesville Consolidated field. In the north end of the field, light showings of oil have been encountered in several wells between 800 and 1,000 feet in depth; however, none of these has been of economic value. In the southeast part of the field, in Sec. 7, O-21, a Pennsylvanian sand at 960 feet currently produces oil in three wells and a small amount of gas in a fourth well. The gas well initially produced 1,500 M. C. F.[3] The three oil wells initially produced 20, 20, and 69 barrels of oil per day, respectively. The Ashland's Wheatley No. 1-A, which initially produced 69 barrels of oil, has an accumulated production of 7,103 barrels of oil in approximately 2 years.

The Pennsylvanian sands as a whole are very erratic and are more nearly bar-type lenses than blanket bodies. Apparently for this reason, there are no large accumulations of oil in the Pennsylvanian of this area.

Mississippian

Chester

Menard.—Over most of the Hitesville Consolidated field, the Menard limestone is the first Chester marker. The Pennsylvanian-Chester contact is marked

[3] M.C.F., 1,000 cubic feet.

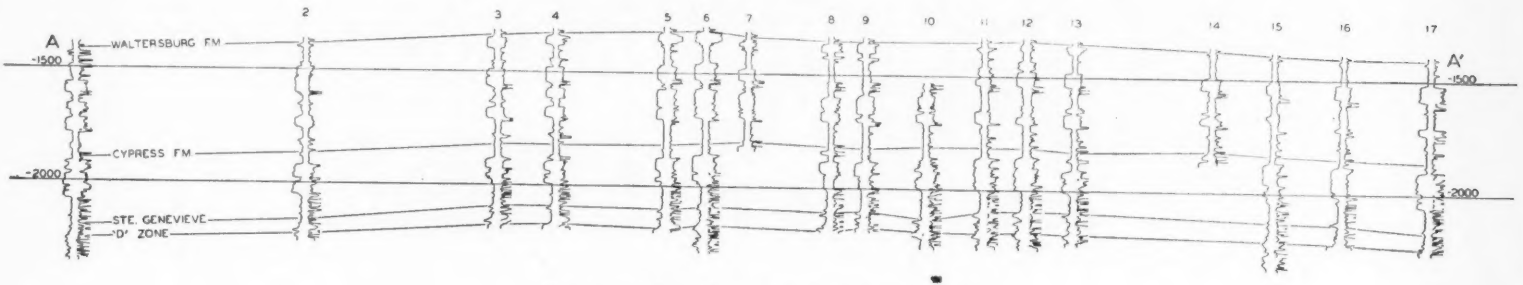

FIG. 4.—North-south electrical log cross section *AA'*.

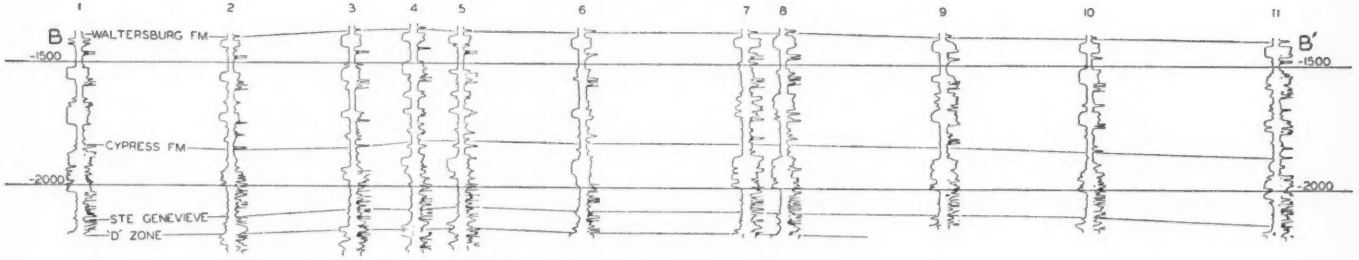

FIG. 5.—North-south electrical log cross section *BB'*.

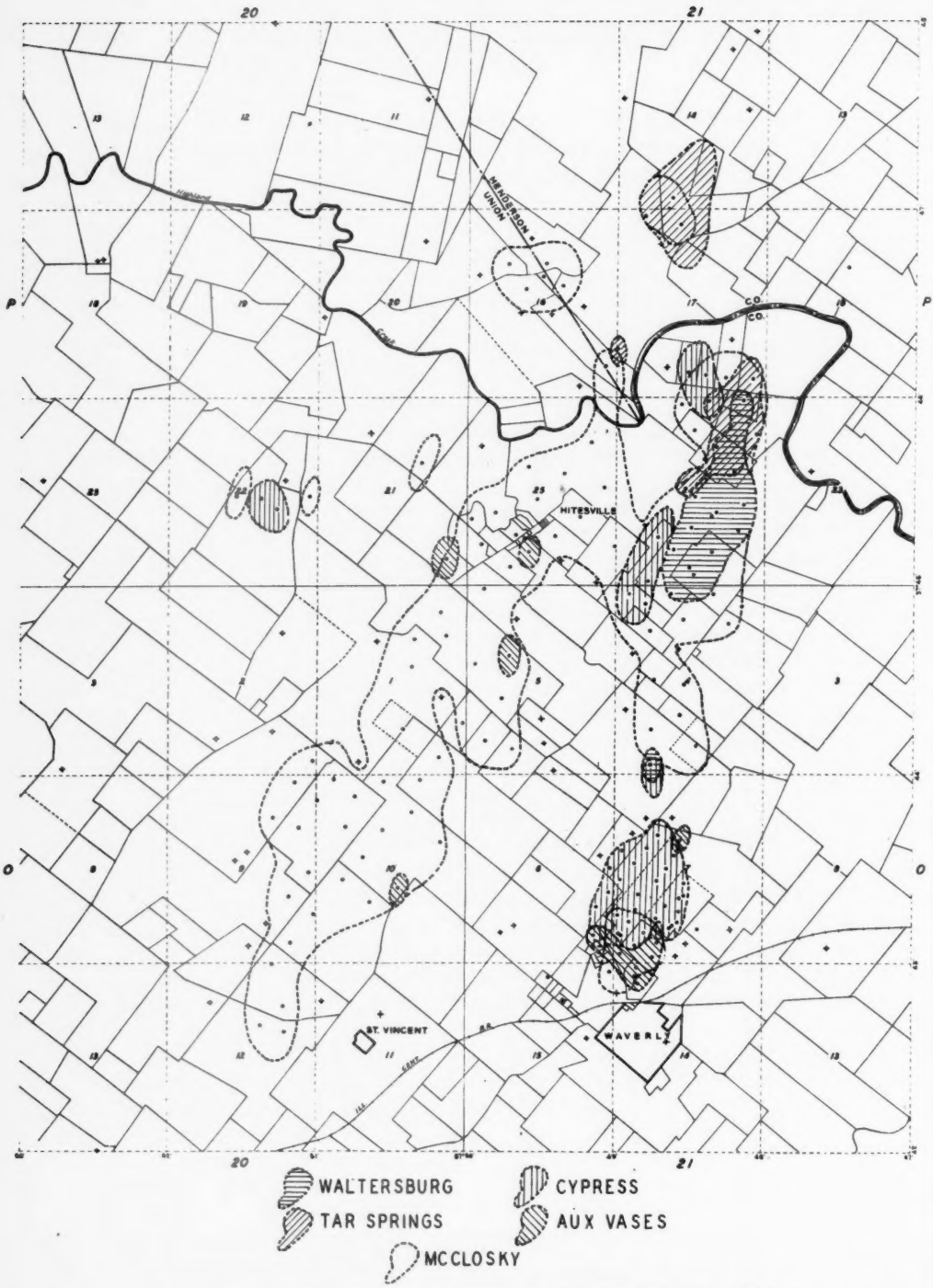

FIG. 6.—Productive outline of each producing zone in Hitesville Consolidated field.

by an erosional unconformity. In part of the field, as much as half of the Menard limestone is missing, and in other parts of the field all of the limestone is present and some Chester shales above are present. The base of the Little Menard limestone maintains a constant position in the upper part of the Chester section; consequently, it is a good formation marker on which to map structure (Fig. 7).

WALTERSBURG.—A thick body of Waltersburg sand is present throughout the field, the exceptions being the southeast part (the original Waverly pool), where there is no good sand, and a part of the north end where the sand body is broken and shaly.

The productive area of the Waltersburg sand is on only the very highest part of the structure in Sec. 24, P-21, and covers 350 acres. The oil-water contact was established at −1,355 feet with the combined assistance of core analyses, drill-stem tests, and electrical logs. However, it was subsequently found inadvisable to complete wells below −1,345 feet because of the high vertical permeability of the sand which is approximately two-thirds that of the horizontal. It was found advisable to prorate each Waltersburg sand well to 40 barrels of oil per day to prevent water coning and subsequent loss of production.

The Waltersburg sand was encountered highest in the Carter's Culver Heirs No. 4 at −1,318 feet, which gives an effective oil column of 37 feet.

Two interesting experiments have been made in the developing and producing of this Waltersburg sand body. One was the drilling of two Waltersburg wells using oil-base drilling mud to prevent the ill effects of allowing water to come into contact with the face of the producing formation. Results of this experiment as yet are not thoroughly conclusive; however, water production from the two wells has been low. The additional expense involved will probably limit the wide use of oil-base mud in this area. The other experiment was the pumping of oil back into the formation of a well which had been affected by water coning. An attempt to break down the effect of the water cone in this experiment resulted in only minor relief from the excess water.

TAR SPRINGS.—The Tar Springs sand is productive in the north part of the field in two local areas. In the north area the lower Tar Springs sand has an effective water drive resulting in wells of potentially high yields. At present there are only three producing wells; however, several more are being drilled and completed. The other area of Tar Springs sand production is about 1 mile south and produces without water drive from an isolated upper sand lens. The sand lens has maximum thickness of only 20 feet, and covers 200 acres. Initial potentials are low, and the decline is rapid.

In several areas in the field there is practically no Tar Springs sand; and in others the sand is as much as 120 feet thick with no showing of oil.

HARDINSBURG.—The Hardinsburg sand is of no economic value. No oil showing of value has been encountered and the erratic nature of the sand is not conducive to the accumulation. However, in parts of the south half of the pool, the Golconda limestone is partly or entirely replaced with porous Hardinsburg sand. This indicates either a period of local erosion or of non-deposition of the limestone.

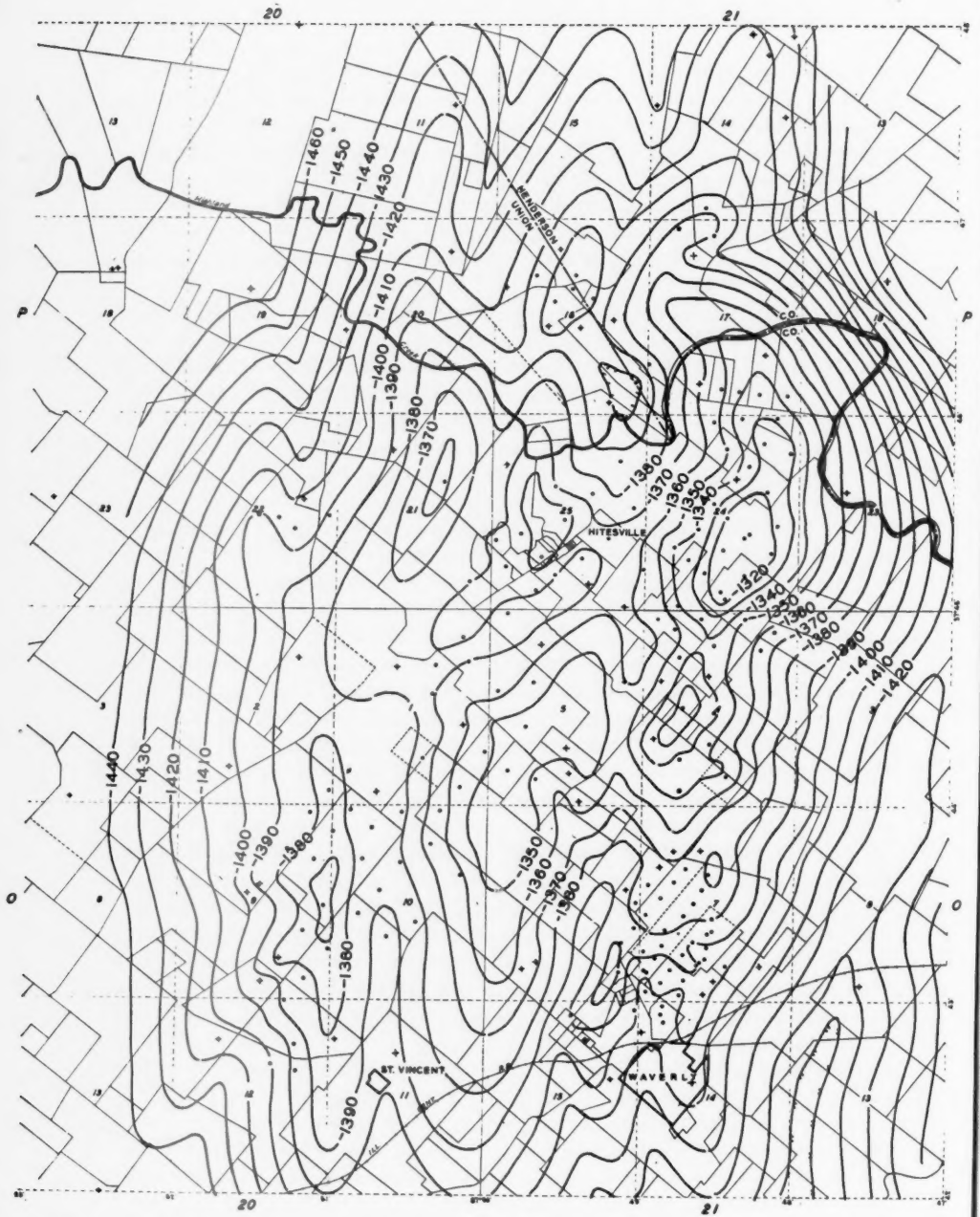

FIG. 7.—Structure map of Hitesville Consolidated field contoured on Waltersburg formation, 10-foot interval.

CYPRESS.—The top of the Cypress formation or base of the Barlow limestone is considered the best marker in the Chester section for mapping structure (Fig. 8).

The Cypress sand produces in three separate areas of the field, the southeast, the central, and the north. In the southeast and in the north, the production is largely from the lower Cypress, and in the central part and in a few wells in the southeast the production is from the upper Cypress.

The upper Cypress sand in the central part of the field is an isolated sand lens apparently having no contact with water from the lower Cypress water-bearing sand. Gas expansion is the motivating force of the oil; consequently, a rapid decline was noted and an early leveling of the production curve. Four wells produce from this sand body, which was discovered in December, 1943, and to November 1, 1947, they had produced 86,457 barrels of oil from 100 acres. The present daily average production is 52 barrels of oil.

The lower Cypress sand in the north part of the field has a water level of −1,893 feet. The same sand less than 1 mile south was encountered at −1,864 feet and did not show oil. However, between the two areas the top of the sand is below the oil-water contact of the producing area. This indicates that the oil had migrated from the north and was trapped at the first barrier instead of going on to the structurally higher area on the south, which incidentally is very close to or underlies the upper Cypress sand. It is possible that the upper Cypress body is connected, or had been connected, with this high area of lower Cypress sand. However, the upper sand has not reacted as if connected with any large source of energy. If this connection were present, it would simplify the explanation of the source of the oil in the upper sand as well as explain why the lower sand is found so high and yet non-productive. Only four wells produce from the lower Cypress sand of the north end; however, three other wells have pipe set through questionably productive sand.

The lower Cypress sand of the southeast end of the pool has an area of 220 acres and is larger than the other two Cypress producing areas. Twenty wells produce from the lower Cypress and five are combination upper and lower Cypress wells. In this case, the upper Cypress sand is present over the structurally highest part of the local area.

A condition of note is the absence of upper and lower Paint Creek limestone. The absence of limestone is also noted at Uniontown, Smith Mills, and across the Ohio River in Indiana. In a few places in this band the entire section is sand from the Barlow limestone to the Renault limestone, a maximum of 200 feet of sand having been noted. The absence of limestone and the presence of sand indicates a possible off-shore channel during Paint Creek time, then subsequent deposition of sand in Cypress time. The sand in this area grades from medium- to coarse-grained, with some tight slightly shaly to quartzitic streaks. The sand varies in thickness as much as 100 feet in a distance of 1 mile. In some areas it is possible to identify the Bethel sand at the base of the thick Cypress body, but in as many places the sand is continuous. It has been very difficult to obtain a typical set of samples through this thick Cypress sand body, because of apparent contamina-

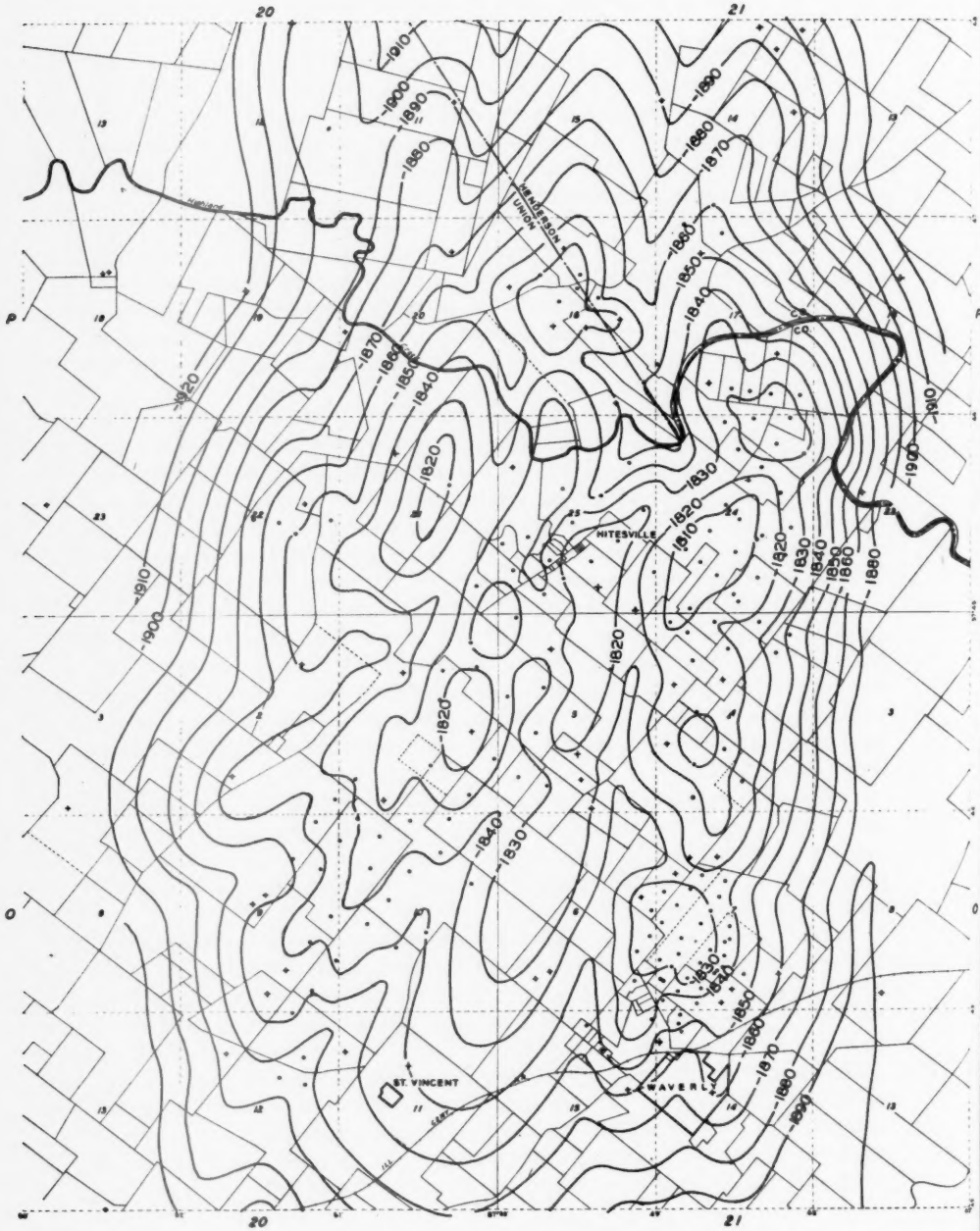

FIG. 8.—Structure map of Hitesville Consolidated field, contoured on Cypress formation, 10-foot interval.

tion of the drilling fluid by the presence of a gypsum-type mineral which fluffs the drilling fluid to such a viscous state that samples are not deposited in the sample trough. For this reason, the best interpretation of the sand section is made from the electrical logs.

RENAULT LIMESTONE.—The Renault limestone is brown to buff crystalline limestone, 20–45 feet thick. Its base has a distinctive lithological character that has been observed over most of the Hitesville Consolidated field, as well as most of western Kentucky in the basin area. The bottom 5–15 feet appears to be reworked brown limestone, mostly in the form of small round to oblong pellets cemented with tan to brown limestone containing varying amounts of small sand grains. Very commonly enough red and maroon shale is included to stain the calcareous pellets and cementing material any shade of brown to red. Below the Renault limestone are 2–15 feet of red, green, and gray shale, and directly below the shale is the Aux Vases formation, which in this area is buff crystalline to oölitic limestone known as either lower Renault or Aux Vases limestone.

AUX VASES SAND.—Aux Vases sand is productive in four isolated areas and in only one of these areas is there more than one well. The area in the vicinity of the old Waverly pool, Sec. 7, O-21, has seven Aux Vases wells, none of which can be classed as a good oil producer. The sand contains water in few, if any, places in the field area; consequently, the motivating force of the oil is only gas expansion, which does not cause large production in a small sand body. Over most of the field, no good sand is present, but only slightly sandy limestone or shale or fine gray-green calcareous sand.

IOWAN

STE. GENEVIEVE.—The top of the Ste. Genevieve is placed on the first limestone below the position of the Aux Vases sand. This point possibly is not correlative with the top of the Ste. Genevieve as recognized elsewhere throughout the Illinois basin, but it is uniformly consistent in western Kentucky, primarily in Henderson and Union counties. A definite lithological change in the limestone may be observed at this point, the limestone below being buff to white oölitic limestone with finer texture and fewer impurities than the limestone above. This point in the section apparently marks a slight erosional surface which is noticeable in the northwest part of the field (Fig. 10).

MCCLOSKY.—In the early stage of development in Hitesville, difficulty was encountered in identifying the various McClosky zones of production. To facilitate the identification of the zones, Carter Oil Company geologists assigned letters to them; thus, we now have productive zones "A" through "G." Of the 146 producing wells in the field, 87 are producing from one or more McClosky zones. Eight of these are producing from three zones, 35 are producing from two zones, and 44 are single-zone limestone producers (Fig. 9).

"A" zone.—The "A" zone occupies the same position in the section as the Levias, that is, the position below the top of the Ste. Genevieve and above the Fredonia. The Rosiclare also overlies the Fredonia, but it has been productive only in a very few places. In the southwest part of the field, in the old St. Vin-

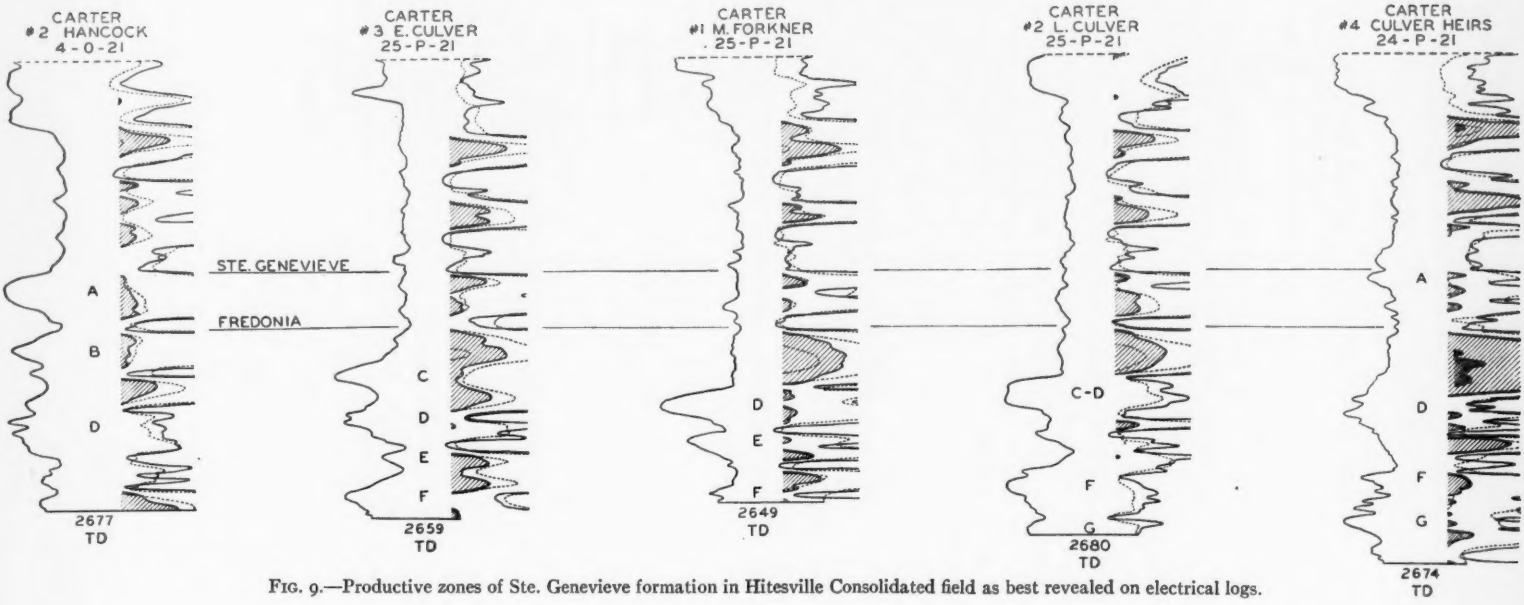

FIG. 9.—Productive zones of Ste. Genevieve formation in Hitesville Consolidated field as best revealed on electrical logs.

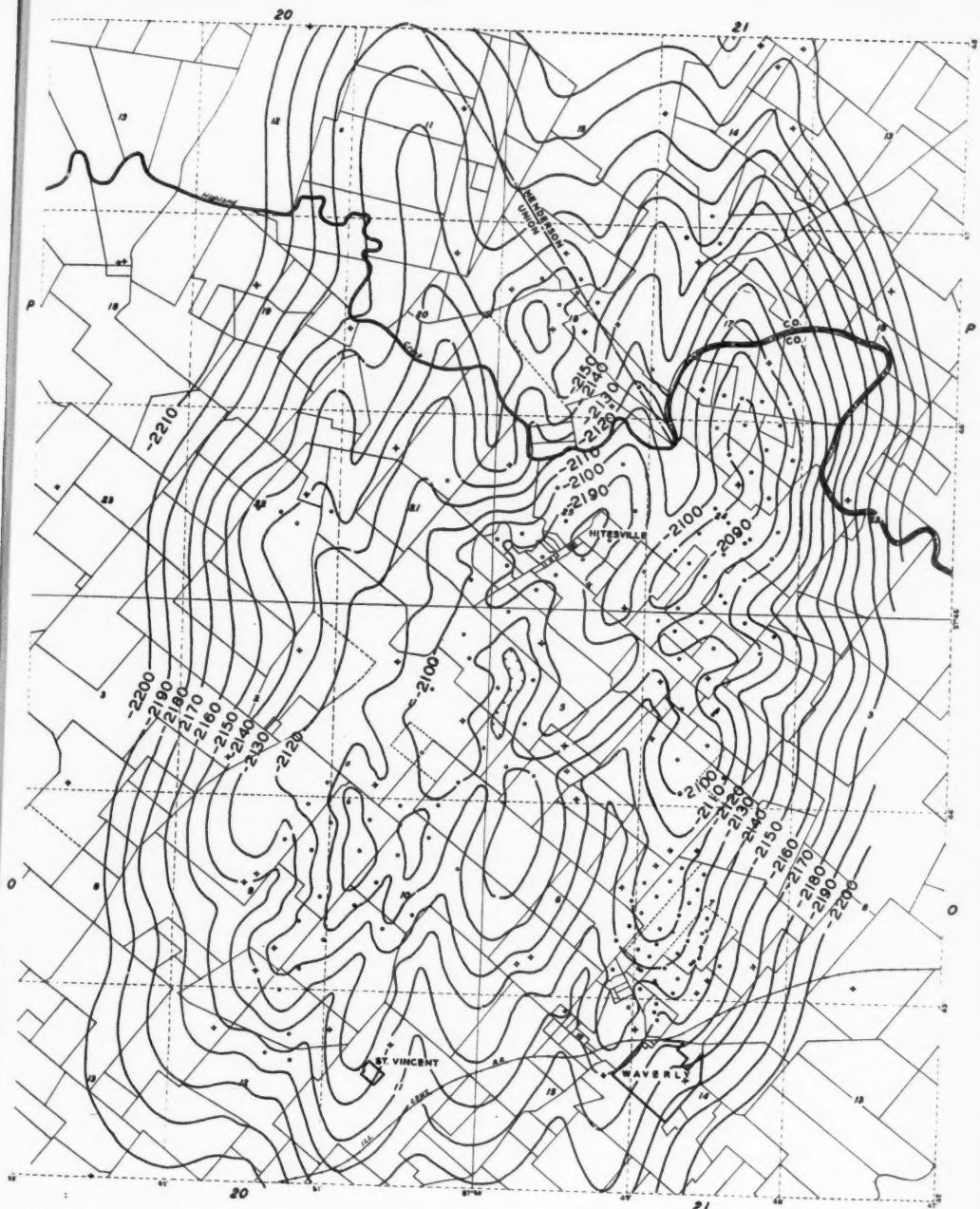

FIG. 10.—Structure map of Hitesville Consolidated field, contoured on Ste. Genevieve formation, 10-foot interval.

cent pool, the "A" zone is in two parts, the lower of which is correlative with the Rosiclare. However, no sand is present, and both are designated "A" zone. The productive "A" zone varies in thickness from a few feet to 18 feet, and varies in porosity from poor to very good. The oölites of the "A" zone are small, well rounded, and have small light-colored centers. Twenty-six of the 87 McClosky wells are producing from the "A" zone, and most of the wells are in the south half of the field. An analysis of cores from 13 feet of productive formation in one McClosky "A" zone well showed the average permeability was 378 millidarcys, the maximum horizontal permeability 1,610 millidarcys, and the maximum vertical permeability 1,290 millidarcys. The average porosity was 13.5 per cent, and the maximum 18.6 per cent. The average residual oil saturation was 16.7 per cent of the pore space, and the average total water saturation was 38.5 per cent of the pore space. This analysis was made of cores taken between 2,525 and 2,548 feet in the Carter's J. C. Hancock No. 2 in Sec. 4, O-21. This well is probably considerably above the average for the 26 "A" zone wells and has been a very good producer in the 2 years since its completion, having recovered in excess of 74,000 barrels of oil from the "A" zone and 6 feet of the "B" zone.

A small amount of water is produced from the "A" zone, thus probably materially aiding the gas-expansion drive which is, in effect, depleting the reservoir. The gas with "A" zone oil is sweet, low in sulphur, and readily usable as fuel for gas engines pumping the wells. In more than half of the field, the "A" zone is either absent, highly dolomitized, or present in the form of dolomite. In several of the wells in the highest part of the structure, the dolomite in this zone is highly saturated with oil. However, the permeability and porosity are so low that no oil can be produced.

"B" zone.—The "B" zone is directly below the top of the Fredonia and attains maximum thickness of 14 feet in the Carter's Hagan Unit No. 1 in Sec. 4, O-21. The Fredonia is a good formation marker in the Ste. Genevieve and can be recognized in most wells in Henderson and Union counties, Kentucky (Fig. 11). This zone, similar to the "A" zone, is found primarily in the south half of the field and is productive in 29 of the 87 McClosky wells. A core analysis has been made for only one "B" zone producer, the Carter's Hancock No. 2. The analysis of 9 feet of core from 2,569–2,578 feet indicated 5 feet of productive formation with an average permeability of 84 millidarcys, maximum horizontal permeability of 389 millidarcys, and maximum vertical permeability of 192 millidarcys. The average porosity was 13.2 per cent, the average residual oil saturation was 20.6 per cent of the pore space and the average total water saturation was 32.5 percent of the pore space. This well is average to possibly a little below average for the "B" zone in the field. As is true with the "A" zone, this zone produces a small amount of water; however, no water level has been established in either zone. A gas-expansion drive is present, and very little assistance is derived from the small amount of water. The gas is sweet. The oölites are small to medium in size, ordinarily well rounded and having either dark or light-colored centers. Dolomitization has affected this zone in a very few places.

"C" zone.—The "C" zone is 25–30 feet below the top of the Fredonia and

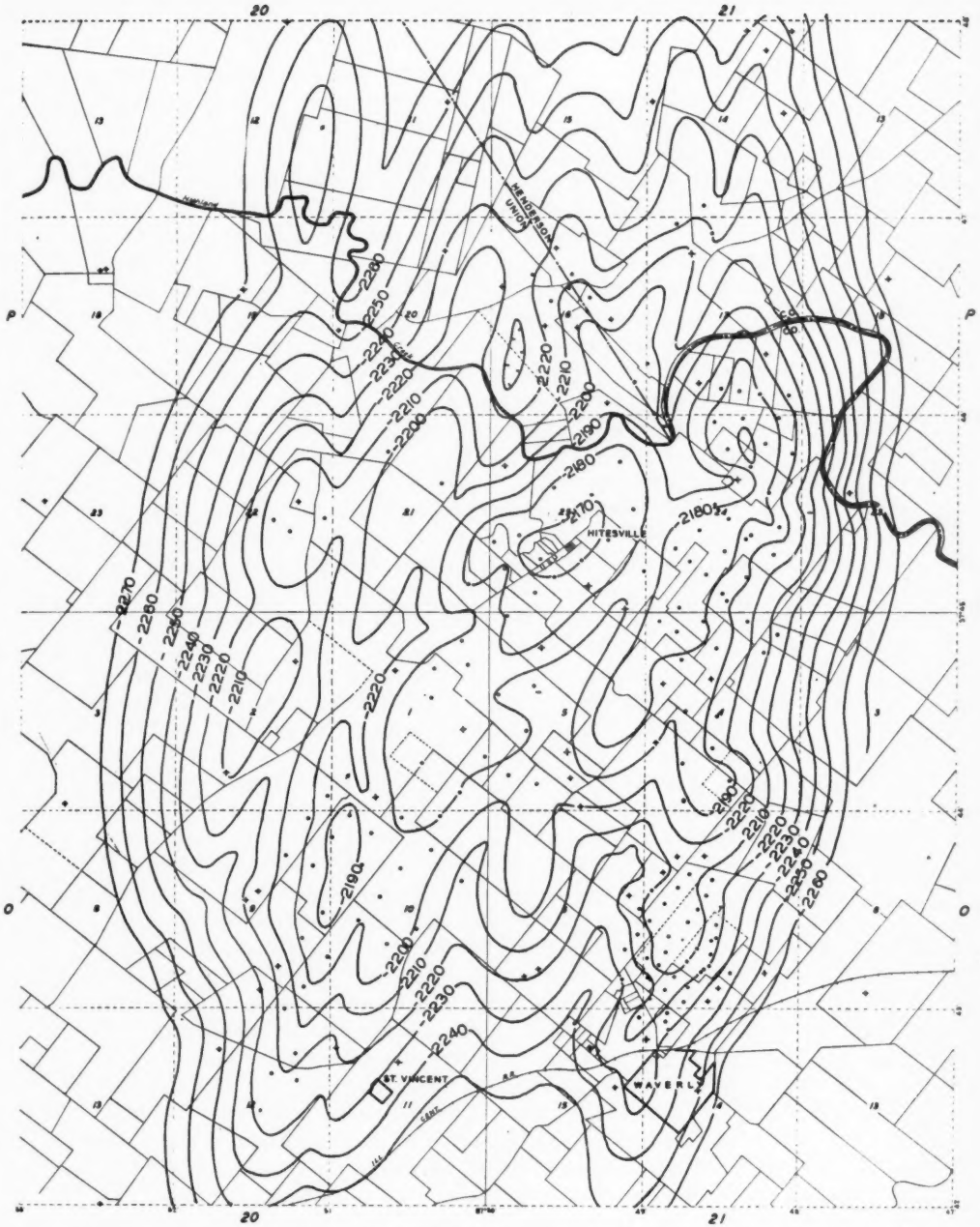

FIG. 11.—Structure map of Hitesville Consolidated field, contoured on Fredonia formation, 10-foot interval.

averages 6½ feet in thickness. Thirty-six of the 87 McClosky wells produce from the "C" zone, and the zone has been productive in every part of the field although not as a continuous, porous body. The productive areas are rather small, but are scattered through most of the field. No core analysis has been made of this zone; however, production history has shown the zone to be highly permeable and to have more than average porosity for an oölitic limestone reservoir. No water has been found; consequently, only a gas-expansion drive is present, causing production to be less than from a zone which has an effective water drive. The oölites are of two varieties: large brown dark-centered oölites, and medium, buff, light and dark-centered oölites. The large brown oölites are at the top of the zone, and commonly are too tight to produce; however, where porous, they are very friable and highly productive. The medium-sized oölites are like those in other parts of the section with the exception that the centers of some are very large in comparison with the size of the oölite and are composed of dark shale or carbonaceous material, and vary from round to oblong. The associated gas is sweet. Dolomitization does not affect the "C" zone.

"D" zone.—The "D" zone is the most prolific zone in the field. It also is the most widespread; however, only 34 of the 87 McClosky wells produce from the zone. This zone can be found throughout the field; a map contoured on the top of the zone is shown in Figure 12. The zone is 3–10 feet under the "C" zone; or, if the "C" zone is absent, it is 45–50 feet below the top of the Fredonia. The "D" zone produces primarily on the top of the structure; however, it is productive in one locality on the southeast flank. The productive thickness of the zone is limited by a water level that varies from north to south. In the north end, the water level is at −2,187 feet; in the central part it is at −2,192 feet; and in the southeast part of the field, it is at −2,225 feet. The entire porous oölitic section of the "D" zone varies from 10 feet to 25 feet; however, 20 feet is the maximum productive thickness. Analyses have been made of cores from two wells in this zone: the Carter's Ed Culver No. 1 in Sec. 5, O-21, and the Carter's Drury No. 4 in Sec. 1, O-20. In the Ed Culver No. 1, the average permeability was 228 millidarcys, the average porosity was 15.4 per cent, the average residual oil saturation was 14.4 per cent of the pore space, and the average total water saturation, was 33.9 per cent of the pore space. In the M. Drury No. 4, the average permeability was 558 millidarcys, the average porosity was 18.5 per cent, the average residual oil saturation was 14.8 per cent, and the average total water saturation was 33.0 per cent of the pore space. These two sets of core-analysis data are representative of an average "D" zone well and a good "D" zone well, respectively.

Water in the "D" zone has considerable pressure and has been known to flow on drill-stem test. The fluid and gas are characterized by high sulphur content. The combined gas expansion and water drive result in considerably higher recovery in the "D" zone than in the zones above. For example, the Carter's Culver Heirs No. 3 in Sec. 24, P-21, has recovered in excess of 103,000 barrels of oil from 5 feet of producing zone since December, 1943. The well currently produces 52 barrels of oil a day and a small amount of water which it has been producing for the last 2 years.

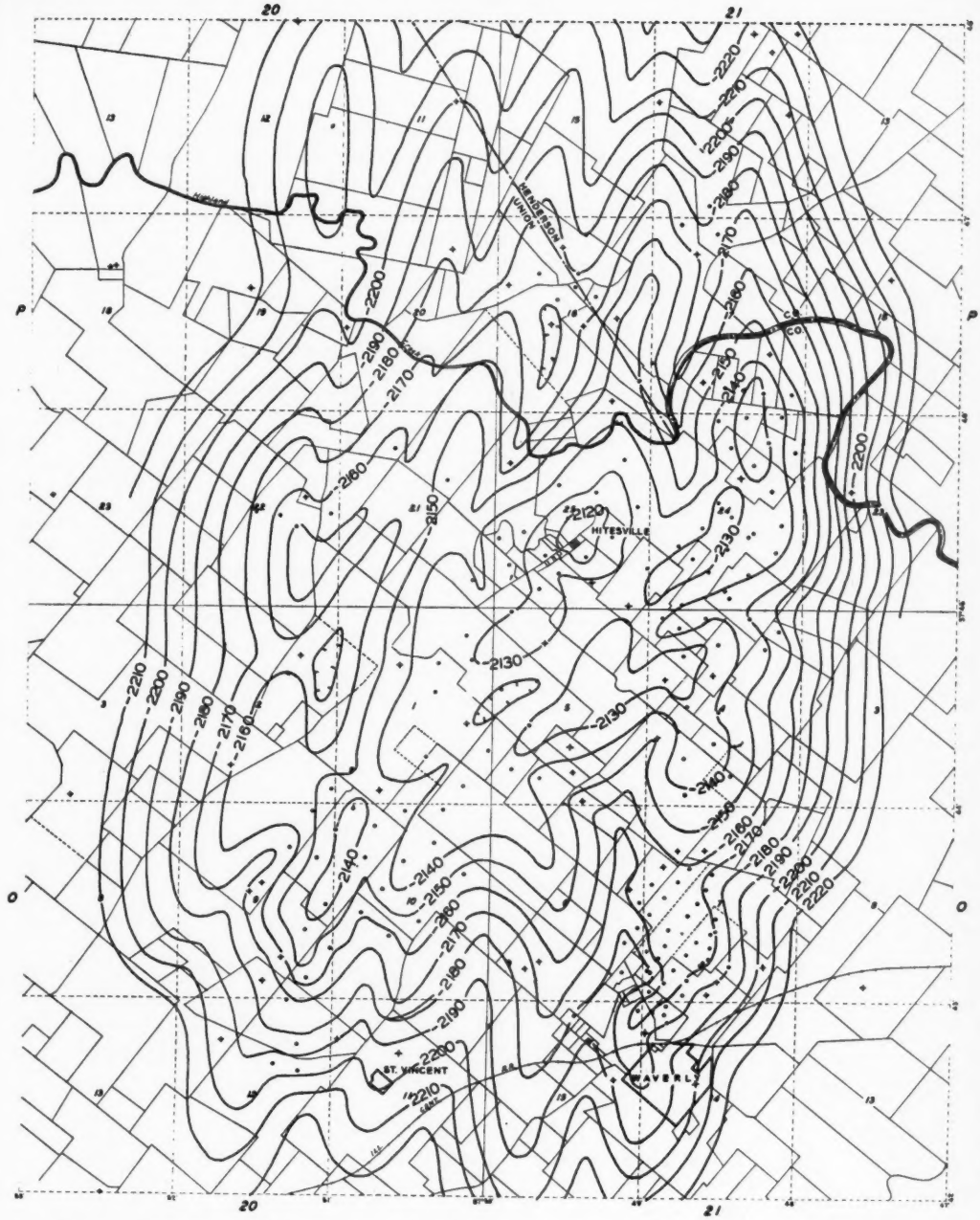

FIG. 12.—Structure map of Hitesville Consolidated field, contoured on McClosky "D" zone, 10-foot interval.

The zones from the "D" zone down are all affected by dolomitization, especially in the higher parts of the field. The oölites are small, white to buff and have light-colored centers. In places, the oölites grade from pure calcareous oölite to dolomitized oölite, to dolocast, and to pure dolomite, indicating that the dolomite associated with the zone is secondary. The greater the percentage of dolomitization, the smaller the percentage of porosity until there is no porosity or permeability present and the zone is non-productive.

"E" zone.—This zone is 70–80 feet below the top of the Fredonia, and is productive in only four wells in the field. These are all in the west-central part of the field near Hitesville. The productive thickness is 6–10 feet. The porosity and permeability are only average and the productive history has been very difficult to follow because the wells are dually completed with other zones. A small amount of water was noted in the initial tests of the zone; therefore, it may be assumed that there is some water drive in this small reservoir.

"F" zone.—The "F" zone is approximately 100 feet below the top of the Fredonia and is productive in five wells in the west-central part of the field and in two wells in the southeast part. This zone is 3–11 feet thick, and has average porosity and permeability. The water level in the west-central part of the field is at −2243 feet. This zone, similar to the "E" zone, is difficult to evaluate because of dual completions.

"G" zone.—The "G" zone is productive in only one well, the Carter's Lenora Culver No. 2 in Sec. 25, P-21. The zone is 130 feet below the top of the Fredonia, or 165 feet below the top of the Ste. Genevieve. Stratigraphically, this is the lowest zone of McClosky production in western Kentucky. It initially produced 257 barrels of oil after treatment with 1,000 gallons of acid.

Origin.—Oil is believed to be indigenous in most of the McClosky zones; however, in the "D" zone, migration from more distant source beds may have taken place.

Dolomitization.—It has been noted that dolomitization has taken place in the higher parts of the structure. Also, thin beds of pure dolomite are present in the Ste. Genevieve. Possibly some of these thin dolomite beds are primary dolomite; but, with the gradational changes shown in the dolomitization of some of the oölite beds, it is possible that all of the dolomite is secondary.

St. Louis.—Three wells in the field have been drilled into the top of the St. Louis and have found the limestone to be brown and dense to slightly crystalline. Amber to milky chert is associated with the top of the St. Louis. The chert is apparently in the form of pebbles or nodules rather than in bands. Some slightly oölitic structure has also been noted in this limestone.

Deeper Possibilities

The Devonian, the Trenton, and the Knox dolomite are the three best deeper possibilities in western Kentucky. These three possibilities are practically unexplored, only a very few wells having been drilled to the Devonian and none below.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2083-2126, 3 FIGS., 3 TABLES

ORIGIN OF RED-BANDED EARLY CENOZOIC DEPOSITS IN ROCKY MOUNTAIN REGION[1]

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ABSTRACT

Red-banded early Cenozoic formations in the Rocky Mountain region are principally fluviatile, piedmont and valley-flat deposits which accumulated in a warm, humid lowland environment that prevailed in the tectonic basins.

Differential thermal analyses of the clay complex of twenty-two red and drab mudstone and sandstone layers reveal that illite is the predominant clay mineral group in most of the tested specimens; kaolinite is the principal clay mineral group in four. A small amount of montmorillonite is commonly present.

Chemical analyses of red and drab layers show a higher Fe_2O_3 content in the red beds. Presumably the red pigment is hematite. Inasmuch as brown hydrated ferric oxide is not known to dehydrate to hematite under conditions prevailing at the earth's surface, the hematite in the red layers is interpreted as primary, derived either from older red formations exposed at the basins' margins or from red soil developed on the surrounding uplands.

A review of the lithologic characteristics and stratigraphic relationships of the variegated formations, together with the paleobotanical evidence of a warm, humid early Cenozoic climate, suggests that red upland soil was transported into the basins. Hence, it is postulated that in deposits which accumulated in more open country of a savanna environment the primary red color was preserved, while in sediments accumulating in heavily forested areas drab colors resulted from reduction of the hematite by incorporated plant débris. As the aggrading streams meandered across the basin floors the sites and environments of deposition constantly shifted, thus producing the alternation of lenticular red and drab strata.

INTRODUCTION

From the time of the earliest geological explorations of the West frequent reference has been made to the origin of the red-banded early Cenozoic formations that crop out extensively in the Rocky Mountain region. Even though these deposits are preserved mainly in tectonic basins throughout a vast area from Montana to New Mexico, in formations a few hundred to 5,000 or more feet thick, their lithologic characteristics and stratigraphic relationships are sufficiently similar to suggest a common mode of origin. This inference may be erroneous, however, serving to obscure the solution of the problem of their origin.

Three hypotheses have been proposed to account for the red layers in these varicolored fluviatile deposits. According to one, the sediments were derived from red Triassic rocks exposed at the borders of most of the basins; according to another the red strata were derived from red upland soils. A third hypothesis attributes the red color to chemical changes during and after deposition of the sediments in an arid or semi-arid environment.

A satisfactory theory of the origin of the red layers must take into account the nature of the source material and the environment of the source area, the

[1] Manuscript received, May 26, 1948.

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agent of transportation, the environment and mode of deposition, and any subsequent changes that may have affected the color of the sediments. Yet few of the interpretations which have been presented have considered more than one of the determining factors.

It is the purpose of this paper to criticize these propositions in the light of recent studies of soils and redbeds, and of analyses of early Cenozoic floras and faunas. The data presented here, many of which are derived from observations and analyses of the Willwood formation in the Bighorn Basin, Wyoming, support the conclusion that the variegated fluviatile sediments were derived from red soils developed on the surrounding uplands, and were deposited in a humid, warm-temperate to subtropical lowland. The red pigment was preserved where little organic matter was incorporated in the flood-plain deposits of the aggrading streams, whereas the drab color resulted from reduction of the ferric oxide in sediments rich in decomposing plant débris.

Two explanations are offered to account for the necessary difference in quantity of the incorporated organic matter. Alternating periods of constantly humid and seasonally humid climates may have been the factor controlling the abundance of vegetation. On the other hand, the drab layers may have been deposited in forest swamps and heavily wooded areas of a savanna environment, while the redbeds were accumulating in the more open country.

The following early Cenozoic deposits in the Rocky Mountain region (Table I) are typical red-banded formations, commonly described as variegated or varicolored: the Galisteo formation in north-central New Mexico; the Puerco,[3] Torrejon,[3] and San José formations in the San Juan Basin in northwestern New Mexico; the Huerfano formation in the Huerfano Basin in south-central Colorado and the DeBeque formation in the Piceance Creek Basin in northwestern Colorado; the North Horn (late Cretaceous in part) and Colton formations on the Wasatch Plateau in Utah; the "Wasatch," Uinta, and Duchesne River formations in the Uinta Basin in northeastern Utah; the Almy and Knight formations of the Wasatch group in the Bridger Basin, and the "Wasatch" formation in the Washakie, Great Divide, Hanna, and Laramie basins in southern Wyoming; the Indian Meadows, Wind River, and Aycross formations in the Wind River Basin in central Wyoming; and the Willwood formation in the Bighorn Basin in northwestern Wyoming. (See Wood *et al.*, 1941, for a brief discussion of these rock units and a bibliography of important references.)

Part I. General Description

Red-banded formations consist mainly of varicolored mudstone, beds of sandstone, and locally abundant conglomerate lenses. Viewed from a distance the color-banding appears regular and parallel (Figs. 1, 2), but close observation reveals considerable variation in detail. (See Hewett, 1926, Pl. 18, for typical strati-

[3] It would seem simplest, most practical, and most logical to consider this part of the stratigraphic sequence as the Nacimiento formation containing the markedly different Puerco and Torrejon faunas (Simpson, 1948, p. 272).

TABLE I

TYPICAL RED-BANDED EARLY CENOZOIC FORMATIONS IN ROCKY MOUNTAIN REGION
(Mainly after Wood *et al.*, 1941)

		Bighorn Basin	*Wind River Basin*	*Bridger Basin*	*South-Central*	*Uinta Basin*	*Wasatch Plateau*	*Piceance Creek Basin*	*Huerfano Basin*	*San Juan Basin*	*North-Central*
		Wyoming				*Utah*		*Colorado*		*New Mexico*	
Eocene	L					Duchesne River					Galisteo
						Uinta					
	M		Aycross						Huerfano		
	E	Willwood	Wind River	Knight	"Wasatch"	"Wasatch"	Colton	DeBeque		San José	
			Indian Meadows								
				Almy							
Paleocene	L										
	M						North Horn			Torrejon	
	E									Puerco	
Cretaceous											

graphic sections.[4]) Interfingering, lateral variation, and gradation in color and grain-size are common, making a comparative study of sections particularly difficult. Most variegated layers are lenses of soft mudstone and fine-grained sandstone differing considerably in thickness and horizontal extent. Generally

FIG. 1.—Willwood formation, Bighorn Basin, Wyoming. Valley wall is 200 feet high.

FIG. 2.—Wind River formation, Wind River Basin, Wyoming.

they are only a few feet thick. Few are more than 25 feet thick or traceable more than several miles.

The colors are usually described as shades of gray or bluish to greenish gray, and lavender, maroon, red, pink, or brown. In the nomenclature of Ridgway

[4] Simpson (1948, pp. 363–74) presents many significant stratigraphic details of the San José formation, San Juan Basin, New Mexico.

(1912) "smoke gray" to "tea green" (commonly weathering "cinnamon-buff") and "brick red" to "liver brown" weathering "ferruginous" are the prevailing colors. More commonly the drab layers have an unevenly distributed carbonaceous content which in places occurs as beds of lignite and paper shale.

Drab lenses generally are thicker and more numerous, the red layers seldom constituting half of a section. Yet, the ratio of red to drab layers varies within thick sections and is different in different parts of the same basin.

In the Wind River formation[5] purple-red layers are most commonly associated with greenish ones, whereas bright red beds generally are found with gray layers (Tourtelot, 1946).

Red beds in the Willwood formation in the southwestern part of the Bighorn Basin (Hewett, 1926, p. 45)

> . . . rarely are more than 8 feet thick and commonly are only 3 or 4 feet; they are interbedded with beds of fine to coarse sand and light colored clay of about the same thickness. No definite succession of beds is invariably present; the most common is (1) gray or buff sand or sandstone, (2) red clay or sandy clay, (3) gray or greenish clay or sandy clay. From this it would appear that the red clay was generally laid down first after a layer of coarser material. There is good evidence that beds of red clay were being deposited in . . . [one locality] at the same time that beds of coarse sand and conglomerate were being laid down in . . . [another].

Stratification of the varicolored sediments is due chiefly to differences in color, for the red and drab beds show a similar range in grain-size, and distinct bedding planes rarely separate successive strata.

Between mudstone layers of different color there is in most places a mottled transitional zone several inches thick. Moreover, in many of the red layers a mottled effect is produced by irregular drab or bleached patches and lines, in some places along minor fractures. The generally accepted theory of the origin of drab patches in red sediments is that the discoloration has been caused by the reduction of red iron oxide during and after deposition by chemical reaction with organic remains incorporated in the deposit. Keller (1929) has demonstrated that the reduction is accompanied by removal of some of the iron in solution.

The difference between the mottling in the red layers and that in the transitional zones appears to be quantitative only, suggesting that both resulted from partial reduction and leaching of an originally red sediment. If this inference is correct, the mottled zones may have been produced in the same way as mottled or spotted tropical soils that result from alteration of red soil and are intermediate between layers where nothing has happened to the ferric oxide and layers where all the ferric oxide is subject to reduction and solution (Mohr, 1944, p. 148). The mottling is thus an intermediate stage in the removal of ferric oxide in the zone of weathering, and generally is produced by conditions of poor drainage.

In some of the mottled zones tubular structures have been found which are 1/16th–1/10th inch in diameter and less than an inch long. Some of the tubes are

[5] Wind River Basin, Wyoming.

filled with drab mud, some with red mud, and in some red and drab alternate in irregular transverse layers. Although these structures have not been studied in detail they are believed to be traces of worms, which corroborates the interpretation of the mottled zones as ancient profiles of weathering under moist conditions, for dry soil is unfavorable for worm activity.

Two inferences consistent with this tentative interpretation of the mottled zones are, first, that sediments of all the mudstone layers originally were red, and, by reduction and leaching, mottled zones and drab layers were produced, and second, that the contact between different colored layers most commonly is a transitional weathered zone and not a sharp contact due to change in the nature of the material deposited.

An extensive bed of limestone is present in the very coarse red and gray "Wasatch conglomerate" on the east slope of the southern Wasatch Mountains (Eardley, 1932). Here, as in limestone lenses in the Wind River formation in the northeastern part of the Wind River Basin (Tourtelot, 1946), abundant oöidal structures undoubtedly are algal growths comparable with "water biscuits" commonly found in modern fresh-water lakes.

In many of the varicolored formations there are thin layers of massive marlstone which probably are lithified organic oozes (Bradley, 1929), although some may have formed during evaporation of temporary lakes (Stearns, 1943, p. 312). Such calcareous deposits point to accumulation in clear, shallow lakes fed by streams carrying a copious supply of dissolved calcium salts.

Concretionary iron oxide and calcium carbonate are common in the variegated mudstone layers, both in nodular form and encrusting fossil bones and shells. According to Tarr (1921) encrusting concretions in relatively impervious sediments were formed during or only shortly after deposition of the enclosing rock.

A 6-inch layer of fibrous hematite composed of spherical particles about 1.2 millimeter in diameter and a 2–3-inch layer of irregular pea-size nodules of limonite with a minor amount of wad have been found in the Willwood formation. Sinclair and Granger (1914, p. 306) reported cylinders, spherical aggregates, and irregular sheets of wad in gray channel sandstone of the Puerco formation.[6] Leaf impressions are preserved in some of the sheets.

The association of syngenetic calcareous and iron concretions throughout the formations suggests they are similar to concretions formed in soil by groundwater activity in warm, humid climates marked by intense dry seasons (Mohr, 1944, p. 162), like the kankar of the Indo-Gangetic alluvial deposits (Grabau, 1913, pp. 585–86). The concentrations of hematite, limonite, and wad probably were deposited in bogs and swamps with fluctuating water level.

Each red-banded formation contains much coarse material. Throughout the deposits ancient stream channels filled with gray, buff, and brown sandstone lenses have been cut into mudstone layers. Most of the sandstone, as pointed out

[6] San Juan Basin, New Mexico.

by Dapples (1947, pp. 97–98), is basin graywacke (Hewett, 1926, pp. 53–54). Some of it, however, particularly the coarser material near the borders of the basins, is arkosic. Only locally are there layers of sandstone with very regular stratification.

Conglomerate lenses ordinarily are more numerous marginward where variegated mudstone constitutes a relatively small part of the total thickness of the formations. At the borders of some of the basins red-banded strata lie nonconformably on older rocks; in the Wind River Basin and in the northern part of the Bridger Basin coarse variegated sediments rest on the pre-Cambrian cores of the peripheral uplifts (Geological Map of Wyoming, 1925).

The marginal distribution of the conglomeratic facies composed of pebbles of older rocks surrounding the basins indicates that the near-by uplands were the source areas of most of the red-banded sediments. In the northeastern part of the Wind River Basin the lower part of the Wind River formation includes coarse material eroded from Paleozoic strata and the upper part contains pebbles of rocks as old as pre-Cambrian. "Wasatch" deposits in the Uinta Basin were clearly derived from late Paleozoic and Mesozoic formations of the Uinta Mountains at the north. Most of the Uinta B sediments, however, were eroded from an eastern source area, possibly the Park Range, which supplied some granite débris (Stagner, 1941, pp. 284–85).

In the drab upper Polecat Bench formation,[7] pebbles of pre-Cambrian rocks and an abundance of heavy minerals (Stow, 1938) derived from crystalline rocks (red garnet, staurolite, kyanite) show that the source material was not predominantly sedimentary, as when Lance and lower Polecat Bench deposits accumulated. Evidently, before deposition of the red-banded Willwood sediments the peripheral mountain cores were in places stripped of a sedimentary cover which had extended across the sites of the great Laramide uplifts (Bartram, 1939; Heaton, 1937).

Crystalline rocks continued to be the principal source of Willwood sediments, and were the source of much of the red-banded Wind River formation as well (Sinclair and Granger, 1911, pp. 112–13). Abundant limestone and granite pebbles in the Willwood conglomerate probably indicates deep dissection of the upland and erosion of bedrock.

The presence and high persistence of green hornblende in Willwood sandstone and its absence from older deposits in the Bighorn Basin suggests that the Early Acid Breccia in northwestern Wyoming was the source of some Willwood sediments. Moreover, layers of tuff have been reported in the Willwood, Wind River, Aycross,[8] Huerfano,[9] and Uinta B formations. Altered volcanic ash in the form of clay minerals of the montmorillonite group probably is an important constituent of those layers that show the characteristic bentonitic swelling accompanying

[7] Bighorn Basin, Wyoming.

[8] Wind River Basin, Wyoming.

[9] Huerfano Basin, Colorado.

the adsorption of water, such as the tested fine-grained drab sandstone of the Wind River formation (Table III, sample 12).

Variegated deposits commonly have a greater range in grain-size and occur in thinner and less persistent beds than the underlying formations. Nevertheless, the change between the drab Polecat Bench formation and the overlying red-banded Willwood formation is gradational. The principal physical change initiating the Willwood is the presence of red layers. Except for the variegation and the more abundant limestone and granite pebbles, the lower part of the Willwood is similar in composition and texture to the Polecat Bench sediments throughout which a few red lenses occur sporadically.

Upper Willwood strata are more brilliantly banded and more arkosic than lower beds, showing that in the Bighorn Basin the factors controlling accumulation of red layers and arkosic yellow sandstone became progressively more effective. In fact, in most formations red layers are more conspicuous when associated with sandy beds, as well as toward the center of the basins, away from the marginal conglomerate lenses.

At the top of the Willwood formation red lenses are interbedded with dark brown carbonaceous shale and drab mudstone in a transitional zone below typical Tatman lacustrine deposits (Van Houten, 1944, p. 182). The alternation of red sediments with coarse sand, drab mud, and carbonaceous deposits reveals that the red layers accumulated in an environment that differed from the forested lowland and coal swamps of the Polecat Bench deposits and from the open swamps and lakes of the Tatman sediments.

Analysis of Mudstone

Petrographic analysis

> So far as mineralogical composition is concerned the microscope has failed to reveal any essential difference between the variously colored clays (Sinclair and Granger, 1911, p. 115).

Drab mudstone analyzed by Johannsen (1914, pp. 221–22) contained quartz, feldspar, and biotite in an altered groundmass of chlorite and sericite; red specimens were composed of quartz, feldspar, biotite, and an altered ferromagnesian mineral in some, in a groundmass of hematite, sericite, chlorite, and, in some specimens, calcite.

Most of the detrital particles are angular quartz grains. With increasing grain size more quartz and feldspars are present. The color of the rock depends on the color of the clay filling the interstices between the grains. There is no evidence that red clay occurs as a coating on drab clay particles. The colloidal fraction of the red mudstone will slowly settle out as a very fine-grained paste which, as in the red mudstone of the Siwalik series (Krynine, 1937, p. 433), is "irresolvable under the microscope."

By x-ray analysis, anhydrous ferric oxide, hematite, has been determined to be the principal coloring agent in red soils and sedimentary rocks. Although

Rogers (1917, p. 528) had concluded that the pigment occurs as amorphous hematite, distinguishable from the crystalline oxide by the fact that it contains a small amount of water, recent work reveals that most "amorphous" substances are in a "microcrystalline" state (Robinson, 1936, pp. 90–91; Weiser, 1935, p. 33).

IRON OXIDES AS PIGMENTS

Tomlinson (1916) and MacCarthy (1926a) summarized available data on the iron content of red and drab rocks, and showed that red colors are the result of an Fe_2O_3-to-FeO ratio that is greater than 2 to 1 (or FeO/Fe_2O_3 ranges from 0.000 to about 0.5), and drab colors result from an Fe_2O_3-to-FeO ratio less than 1 to 1 (or FeO/Fe_2O_3 exceeding 0.750).

By experiment MacCarthy demonstrated that red, yellow, and brown colors are produced by ferric oxide, natural iron blues by hydrous ferro-ferric compounds (Hager, 1928, pp. 912–17), and grays and black by anhydrous ferro-ferric compounds. Iron green is a mixture of blue hydrous ferro-ferric and yellow ferric compounds.

Dorsey (1926) showed that information concerning the relation of iron compounds to the color of sediments leads to the following conclusions. 1. Red rocks do not owe their color to a greater total iron content than non-red rocks. The shade of color bears no apparent relation to the amount of iron. 2. The mere presence of ferric iron does not by itself produce red color, for many drab sediments have a high ferric iron content. There must be an excess of ferric over ferrous iron, calculated as oxides in most analyses. 3. In general, the state of hydration of the iron compound is an important factor controlling the color of rocks. In order to color sediments red, ferric iron must be in the anhydrous form, hematite, and very finely diffused, permeating the entire rock mass.

The amount of hematite necessary to color a sediment constitutes only a minor part of the rock, but in a state of extremely fine subdivision it is disseminated through the sediment. The pigment of the red mudstone layers is dispersed in the clay complex, for the colloidal fraction of a mudstone sample is nearly the same color as the original specimen. The pigmenting power of the disseminated hematite is demonstrated by the fact that a mixture of equal parts of red and drab mudstone in suspension is a red mud nearly the same color as the original red sample.

Two factors of considerable importance controlling the intensity of red color in sediments have been studied experimentally by MacCarthy (1926b): first, the actual content of ferric oxide, and second, the distribution of the pigment, whether adhering to sand grains or adsorbed by the clay matrix. The actual ferric oxide content of fine-grained sediments, that is, the amount of oxide adsorbed by the clay complex, is proportional to the amount of alkali present up to 5 per cent Fe_2O_3. (But a high ferric iron content does not in itself mean a red color.) In the presence of hydroxides, however, no alkalis are necessary to activate adsorption of ferric oxide, a fact which suggests that tropical and subtropical soils containing

hydroxide clays are thus able to retain ferric oxide, whereas silicate-rich soils of temperate climates, in the absence of hydroxide clays and alkalis, can not, and the iron is removed by ground water.

MacCarthy also found that the distribution of pigmenting material in sandstone is governed by the amount of non-ferruginous colloids present: the higher the percentage of non-ferruginous colloids in a sediment the greater is the amount of iron oxide necessary to color it. The non-ferruginous colloids apparently prevent adherence of the pigment to the sand grains. Instead, the ferric oxide is adsorbed by clay matrix and in this way a greater total surface area available for coloring is presented by the clay particles as compared with that of the sand grains. Generally, among rocks of the same shade of red, the coarser-grained rocks contain less ferric oxide because the larger grains present less total surface area. In other words, a greater amount of pigment must be applied to fine-grained sediments than to coarse-grained ones in order to bring the two to the same shade of color.

CHEMICAL ANALYSIS

The examination of the red and green clays shows a curious difference that may aid in understanding the significance of the color of the fine sediments in the formation. Neither specimen was easily disintegrated, and in each sand portion there were many little hard composite grains or concretions. Those from the red clay were reddish iron oxide with clay, whereas those from the green clay were black manganese oxide almost free from iron. No complete analyses that might show the amount and degree of oxidation of the iron present are available. Commonly the difference in color of such clays is supposed to be due to the difference in the degree of oxidation of the iron present. Sinclair and Granger showed that although some red clays contain about 1.5 per cent more ferric oxide than some blue clays, both varieties contain from 2.77 to 7.91 per cent of ferric oxide and less than 0.58 per cent of ferrous oxide. It seems probable that the manganese content should receive consideration, for it is known that in making brick a clay that normally burns to a bright red can be burned to yellowish gray by adding a small proportion of manganese oxide (Hewett, 1926, pp. 54–55).

Small quantities of manganese oxide occur in most specimens of black and green shale and slate. The amount of manganese appears to bear some relation to the ferrous iron content (Twenhofel, 1932, pp. 566–69, 576–80). Hence, it is important to note that in soils of poorly drained regions, where ferrous compounds are common, oxides of manganese commonly accumulate near the surface (Robinson, 1936, p. 65).

Data in Table II agree with observations of Tomlinson and MacCarthy that even in brilliant red deposits only a very small amount of ferruginous matter is necessary to color the sediment. But assuming that no ferrous iron was oxidized during the analyses, the calculations are at variance with conclusion of these authors that there is a greater proportion of FeO in drab sediments than in red sediments. In all the specimens analyzed there is a preponderance of Fe_2O_3 over FeO. The Fe_2O_3: FeO ratios of both red and drab samples fall within the composition range of red sediments in the data assembled by Tomlinson and MacCarthy.

TABLE II

CHEMICAL ANALYSES OF RED AND DRAB SEDIMENTARY ROCKS*

Sample	*Total Iron Calculated as Fe_2O_3*	*FeO*	*Fe_2O_3*	*Fe_2O_3:FeO*	*FeO:Fe_2O_3*
Mottled, Wind River formation					
RED	8.16	.19	7.91	42	.02
DRAB	6.67	.38	6.24	16	.06
Excess Fe_2O_3			1.67		
Willwood formation					
RED	4.82	.58	4.18	7.2	.14
DRAB	3.34	.52	2.77	5.3	.19
Excess Fe_2O_3			1.41		
Shaly Chugwater formation					
RED	3.56	.28	3.28	11.6	.08
DRAB	2.97	.63	2.34	3.7	.27
Excess Fe_2O_3			.94		
Massive Chugwater formation					
RED	2.24	.49	1.75	3.5	.28
DRAB	1.17	.31	.86	2.7	.36
Excess Fe_2O_3			.91		

* Analyses by A. H. Phillips, from Sinclair and Granger (1911) and Taylor (1932).

The only consistent variable among the data in Table II is found in comparing the iron content of red and drab specimens from the same formation. In each pair of samples the Fe_2O_3 content of the red is greater, and the excess of ferric oxide in red over that in drab is nearly the same as in analyses published by other authors. But in comparison with these reports, there is an exceptionally small amount of FeO in all samples listed in Table II.

That the color of the red layers is related to an excess of Fe_2O_3 over that in drab beds appears to be a valid conclusion. But these data do not substantiate the conclusion that all beds with a high percentage of Fe_2O_3 over FeO are red, or that there is a high proportion of FeO in all drab sediments, as is suggested by the studies of Tomlinson and MacCarthy. In order to appreciate the meaning of the discrepancy between their data and those in Table II it would be necessary to know the chemical state of the non-red ferric oxide in drab rocks, but this information is not provided by available analyses.

DESCRIPTION AND CHEMICAL RELATIONSHIPS OF IRON OXIDE MINERALS

The following data concerning some of the iron oxide minerals are principally from Palache, Berman, and Frondel (1944) and Mason (1943).

Lepidocrocite.—An oxide containing (OH); the hydrated or monobasic ferric oxide FeO(OH) or $Fe_2O_3 \cdot H_2O$, dimorphous with goethite. Ruby-red to reddish brown. Its occurrence and association are the same as those of goethite, but it is much more rare and has

not been recognized in soils. It probably is identical with $\gamma Fe_2O_3 \cdot H_2O$ of Weiser (1935, p. 40). Lepidocrocite is not as stable as goethite, for it dehydrates to αFe_2O_3 (hematite) on grinding and to γFe_2O_3 (maghemite) at 100°C. (Hofer and Weller, 1947). It has been prepared artificially by oxidation of hydrous ferro-ferric oxides.

Goethite.—A multiple oxide, differing from the corresponding hydroxyl mineral, lepidocrocite, in not having the (OH) group and in that the H acts as a cation in two-fold coordination between oxygen, and in being harder and better crystallized. (Bragg, 1937, p. 111, discusses goethite under hydroxides and refers to it as a hydrous oxide. Probably it is neither.) It is generally considered a hydrogen iron oxide, $HFeO_2$ ($\alpha Fe_2O_3 \cdot H_2O$ of Weiser, 1935, p. 39), and is usually called a hydrated ferric oxide, though sometimes a ferric monohydrate or ferric oxide hydrate. Goethite is yellow to brown when earthy, and probably is the pigment of most yellow to brown soils. It is a common alteration product of ferriferous minerals, formed under oxidizing conditions at ordinary temperature and pressure.

Maghemite.—An anhydrous ferromagnetic oxide, γFe_2O_3, with crystal structure and magnetic properties very similar to magnetite (Welo and Baudisch, 1934, p. 56). Typically brown with a brown streak. Maghemite is a monotropic form of Fe_2O_3 that is metastable with respect to αFe_2O_3 (hematite), inverting to the latter at all temperatures. At ordinary temperature the rate of inversion is extremely slow, but at temperatures from 200° to 700°C. maghemite changes readily to hematite. Inasmuch as the reaction is not reversible, maghemite can not be formed directly from hematite. Maghemite generally results from supergene processes in the zone of oxidation and is relatively common as a product of weathering of iron minerals, particularly magnetite, by slow oxidation at surface temperatures, a process favored by tropical conditions. Whether it forms by direct oxidation or by way of the hydrated oxide, lepidocrocite, is difficult to determine in most cases. It is found as a common oxide product of rusting iron and steel. Because maghemite inverts to hematite at high temperatures, it probably does not occur as an original mineral in medium- to high-temperature deposits. In the laboratory maghemite is produced by dehydrating lepidocrocite at high temperature, and by oxidizing magnetite or heating it in air.

The magnetic susceptibility of soils, due to the presence of a ferromagnetic mineral, shows a large variation, according to recent work by Edward Sampson. The association of higher values with red soils and the highest with lateritic iron ore, suggests that the quantity of the ferromagnetic mineral increases toward the lower latitudes. Inasmuch as the mineral occurs in soils developed on limestone, it undoubtedly is a secondary ferromagnetic ferric oxide (possibly maghemite), and not detrital magnetite. Evidence that maghemite is the red pigment in some sandstone is cited by Hofer and Weller (1947).

Hematite.—αFe_2O_3, the stable form of Fe_2O_3, is probably the most abundant and widespread of the iron oxides, and is the only one stable at all temperatures. Up to several per cent H_2O may be present in the fibrous or ochorous varieties; in the latter form it occurs as a dull to bright red pigment in sedimentary rocks. Hematite may change to magnetite in the presence of reducing agents, and magnetite will readily change to hematite under conditions of moderate temperature and sufficient supply of oxygen. Hematite also results from the inversion of γFe_2O_3 at all temperatures.

Turgite.—A hydrous ferric oxide, $Fe_2O_3 \cdot nH_2O$, identical with hematite; in part a metacolloid with adsorbed and capillary water. Dark red to brown; bright red or orange-red when earthy.

Limonite.—A generic term for natural amorphous hydrous iron oxides whose real com-

position is unknown. Its spectra lines frequently are the same as those of goethite but more diffuse and less intense. The substance appears to represent hardened gel masses of hydrous hydrated ferric oxide, $Fe_2O_3 \cdot H_2O \cdot nH_2O$, and in less part hydrous ferric oxide, $Fe_2O_3 \cdot nH_2O$.

For a discussion of the properties and relationships of the iron oxides (Fig. 3), see Mellor (1934, pp. 701–905), Welo and Baudisch (1934), Weiser (1935), and Mason (1943).

In a review of the hydrated ferric oxides Posnjak and Merwin (1919) demonstrated that no series of these oxides exists among natural minerals. Instead, only the monohydrate, goethite and its dimorphous form, lepidocrocite, are well defined physically and chemically. At high temperatures goethite dehydrates to hematite, and lepidocrocite to maghemite; but at any temperature or pressure which the earth's surface may normally reach, the monohydrates probably are stable. It is improbable, therefore, that in nature the red ferric oxide, hematite, is derived by spontaneous dehydration from the brown hydrate, goethite. At ordinary temperatures the red and brown substances are probably formed by somewhat different chemical reactions. Both compounds are relatively stable under conditions prevailing on the earth's surface (p. 339).

It must be remembered, however, that in reviewing the relationship of these minerals, the unknowable but probably important factor of geologic time has not been considered. Hager (1928, p. 921) and Krynine (1947) maintain that hematite can be formed from goethite under surface conditions, as the result of geologic processes. According to Krynine, all the iron in sediments and soils eventually passes into hydrated iron oxide in a non-reducing environment.

The process becomes obscure at this state. Dehydration of yellow iron oxide into red anhydrous oxide takes place at surface temperatures in many of the warm regions, but cannot be duplicated in the laboratory unless much higher temperatures are used.

In 1927 Raymond applied some of these observations to the problem of the red color of sediments, suggesting that, instead of heat affecting dehydration of brown ferric compounds to red ones, warm, moist climates favor those chemical reactions that produce the red compounds directly. Through this approach to the problem, studies of the chemical state of iron in the soil became particularly important.

COLLOID CHEMISTRY OF IRON OXIDE MINERALS

The most common components of soil colloids are kaolin minerals, the illite group, minerals of the montmorillonite group, quartz, goethite, and hematite (Hendricks and Alexander, 1939). In a colloidal state iron oxides exist as particles at least as small as 0.001 mm. in diameter, and in this condition ferric oxides and hydrates form solid solutions with water, coagulate, and crystallize (Polynov, 1937, Table 10). Mixed sols of iron oxide and humus (ferri-humates) in soil will also coagulate if the proportions are altered, and form coagels of humus and hydrated ferric oxide.

In view of the significance of the colloidal complex in soils, a summary of the

characteristics of colloidal iron precipitates is pertinent. Most of the data that follow (Fig. 3) were obtained from laboratory studies of Welo and Baudisch (1934, pp. 45–97) and Weiser (1935, pp. 27–89).

Three distinct forms of ferric oxide have been prepared: a brown hydrous oxide precipitate, and two yellow hydrated ferric oxide precipitates. It has been demonstrated that the hydrous iron oxides are distinct from the hydrated oxides

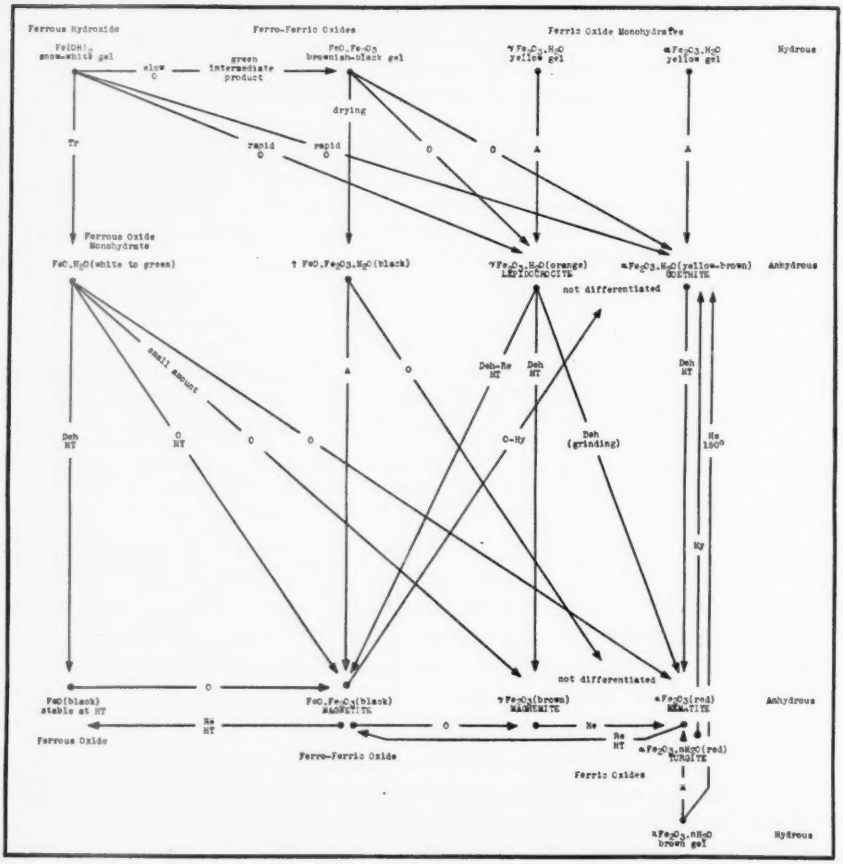

FIG. 3.—Interrelationship of some oxides and oxide hydrates of iron as determined by laboratory studies. In most reactions oxidation and dehydration are considered to be reversible, generally requiring extreme conditions in the laboratory.

HT—high temperature. O—oxidation. Re—reduction. Hy—hydration. Deh—dehydration. A—aging (spontaneous change occurring at normal conditions of temperature and pressure). Tr—transformation on aging. He—heat. Temperatures in degrees Centigrade.

(Polynov, 1937, pp. 106–08), and that there is no hydroxide of ferric iron.

Freshly precipitated hydrous ferric oxide is a brown gel consisting of extremely minute particles of αFe_2O_3 with adsorbed water, and too finely divided to diffract x-rays. On aging, the substance becomes brick-red anhydrous ferric oxide (hematite). Turgite, with its adsorbed water, appears to be an intermediate step in the aging of hydrous αFe_2O_3. At ordinary temperatures the time of aging is a year, but at 100°C. the transformation occurs in less than 16 hours. Aging results in growth and agglomeration of particles and the loss of adsorbed water, producing crystals of αFe_2O_3 large enough to give sharp diffraction lines. Variation in color of the ferric oxide during aging "appears to be due both to the size of the particles and to the crystal structure" (Weiser, 1935, p. 33). In general, minute particles produce a light brown color; when the particles are larger the color is red. Plice (1943) has concluded that the most important factor in the coloration of yellow and red soils is the particle size, density, and degree of agglomeration of ferric oxide crystals, the density and agglomeration being greatest in the reddest soils. He has also pointed out that non-red soils commonly show a high calcium, or other base, content, and that such bases are known to retard agglomeration of hematite.

Three polymorphic forms of hydrated ferric oxide, recognizable by their x-ray patterns, have been prepared as yellow hydrous colloidal precipitates: $\alpha Fe_2O_3 \cdot H_2O$, $\gamma Fe_2O_3 \cdot H_2O$, and $\beta Fe_2O_3 \cdot H_2O$. Each can be dehydrated at high temperature, the dehydration temperature depending in part on particle size and rate of temperature increase.

$\alpha Fe_2O_3 \cdot H_2O$ is identical with goethite, yielding αFe_2O_3 (hematite) on dehydration at high temperature.

$\gamma Fe_2O_3 \cdot H_2O$ (identical with lepidocrocite), the orange-yellow hydrate, yields γFe_2O_3 (maghemite) on dehydration at high temperature. (See also Bragg, 1937, p. 113.) γFe_2O_3 generally is brown, but also, the color varies from yellow to dark red according to particle size and to the form of the granules.

That lepidocrocite and goethite will form simultaneously from the same chalybeate solution, that lepidocrocite is less stable than goethite and may yield maghemite or hematite, and that goethite and hematite and a small amount of maghemite can be prepared from the same chalybeate solution have been clearly demonstrated experimentally by Rayleigh (1946) and Hofer and Weller (1947).

$\beta Fe_2O_3 \cdot H_2O$ yields brick-red αFe_2O_3 on high-temperature dehydration. Because this hydrated ferric oxide is known only from precipitates prepared in the laboratory it is omitted from Figure 3.

In summary, the hydrous hydrated ferric oxides ($Fe_2O_3 \cdot H_2O \cdot nH_2O$) are produced by chemical reactions different from those producing hydrous ferric oxide ($Fe_2O_3 \cdot nH_2O$). Both may be formed as colloidal gels containing excess water. Both may be dehydrated at surface temperature, the former yielding goethite or lepidocrocite, the latter, hematite. Only at high temperatures can the hydrates be changed to anhydrous oxide.

Hydrous ferrous hydroxide, $Fe(OH)_2$, is a snow-white precipitate unstable in the presence of oxygen, and apparently transforms on aging to hydrated ferrous oxide, $FeO \cdot H_2O$. Oxidation of freshly prepared $Fe(OH)_2$ yields $FeO \cdot Fe_2O_3$, $\alpha Fe_2O_3 \cdot H_2O$, or $\gamma Fe_2O_3 \cdot H_2O$, but never any Fe_2O_3. On the other hand, a 4-day old precipitate aged to $FeO \cdot H_2O$ in the absence of oxygen, oxidizes to αFe_2O_3 and some γFe_2O_3.

Recognition of hydrous ferro-ferric oxide precipitates in the laboratory is of particular importance in view of the evidence presented by MacCarthy (1926a) and Plice (1943) that ferro-ferric compounds are the coloring agents of some drab sediments. Hydrous ferro-ferric oxide is a magnetic, brownish black precipitate obtained by slowly oxidizing $Fe(OH)_2$. It has the same x-ray pattern as $FeO \cdot Fe_2O_3$ (magnetite). During the oxidation process a green intermediate product is formed whose composition is thought to be $2FeO \cdot Fe_2O_3$ (Weiser, 1935, p. 89). Polynov (1937, pp. 38–39) has noted other ferro-ferric compounds (αkerchenite, βkerchenite, and oxy-kerchenite) formed by microbial activity during oxidation of ferrous vivianite to ferric beraunite.

IRON OXIDES IN SOIL

In 1942 Raymond stressed the importance of the fact that hematite is formed in the soil at surface temperature and pressure by processes, including the action of bacteria (see also Moore and Maynard, 1929, p. 279; Harder, 1919, pp. 29–31, 36–38), different from those producing the monohydrates. Brown colloidal hydrous ferric oxide, for example, is produced by bacterial activity in soil. On standing, this oxide will change to red hematite by slow, spontaneous crystallization. Because bacterial activity is restricted in cool climates, such a process probably is limited to warm, moist regions.

Alexander, Hendricks, and Nelson (1939) have presented data showing that goethite and hematite are common constituents of soils. Lepidocrocite, on the contrary, does not appear to be a common soil mineral. Although both goethite and hematite are present in red and brown soils, very red soils owe their color to the presence of the hematite (p. 279). The red color is due to hematite crystals of sufficient size, translucency, and degree of agglomeration to produce that color, inasmuch as hematite may be black, gray or brown (Plice, 1946). Light red and yellow soils, for example, may be colored by hematite in a state of lesser degree of agglomeration and a smaller crystal size. Accordingly the intensity of redness of soil is not necessarily proportional to its hematite content.

In highly organic soils the black color may be due directly to the presence of carbonaceous matter in the form of colloidal humus (Polynov, 1937, p. 58). However, in most drab soils the organic matter does not color the sediments, but by causing reduction or preventing further oxidation, is responsible for the presence of ferro-ferric compounds of the colloidal clay constituent that is the pigment. Even in soils colored by humus, the drab colors of the lower horizons may be due

to the presence of such ferrous compounds as pyrite, marcasite, vivianite, and the ferro-ferric silicate glauconite (Robinson, 1936, p. 193).

Bacterial activity is important in creating reducing conditions (or a low oxidation-reduction potential) in soils and sediments. In this process its major role is the formation of humus and humic derivative, principally by anaerobic types. Hydrogen sulphide produced by bacteria may also reduce ferric iron.

> Soils subjected to submergence undergo characteristic changes, provided sufficient organic matter be present. Under these conditions, anaerobic decomposition occurs and rapid losses may ensue. There is also an increase in the solubility of the iron, manganese, calcium and magnesium, which appear in solution as bi-carbonates, the iron being in the ferrous state. The reductive processes result in a change from the red color of well aerated soils to the grey color associated with bottom soils (Robinson, 1936, p. 313).
>
> There is no information to suggest that the reduction of the oxygen compounds of iron . . . is connected with the activity of any particular micro-organism. It is true that these common processes are dependent on the decomposition of organic matter, which is in general microbiological, but the reduction itself is, or may be, a purely chemical reaction. The decomposition products of the organic matter (including hydrogen) take up oxygen from the mineral compounds, and especially the compounds of iron . . . , and reduce them. The localities where such reduction processes are most strongly developed are swamp and lake deposits, moist meadow soils, river valleys, ground water horizons and buried soils . . . (Polynov, 1937, pp. 41–42).

Plice's reports on the factors affecting soil color (1943, 1946) suggest some of the relationships of ferrous and ferric iron in drab soil. Gray soil commonly contains both types of iron in a ferro-ferric complex, and there seems to be no limited ferro-ferric ratio or range of ratios necessary to produce particular gray colors. Ferrous and ferro-ferric iron are relatively unstable and in the presence of colloidal humus and silica they may form hydrated ferromagnesian silicates (Polynov, 1937, p. 138).

> It is now known that iron compounds form essential ingredients in the clay complex, for clays containing notable proportions of iron occur in which the presence of adventitious ferric oxide cannot be assumed. Any theory of the nature of the clay complex must take account of the possible existence of complex ferro- and ferri-silicates and of the possibility of isomorphous replacement of aluminum by iron in complex alumino-silicates . . . (Robinson, 1936, p. 82)

such as montmorillonite and illite groups of clay minerals.

DIFFERENTIAL THERMAL ANALYSIS

Differential thermal analysis of the clay fraction of twenty-two samples from five variegated formations (Table III) reveals that illite (Grim, 1942) is the predominant constituent in eighteen of the samples and kaolinite in four. Montmorillonite is commonly present as a minor constituent. Illite is also the principal clay mineral group in analyzed samples (Table III) of the reddish brown Brunswick and Stockton formations (Triassic, New Jersey), brown Chicopee shale (Triassic, Massachusetts), the red Chugwater and Spearfish formations

TABLE III

DIFFERENTIAL THERMAL ANALYSES OF RED AND DRAB SEDIMENTARY ROCKS

Sample	*Clay Mineral Groups Present*	
	Predominant	*Subordinate*
Willwood formation		
1. Red mudstone[1]	Illite	Small amount of montmorillonite
2. Red mudstone	Illite	Small amount of montmorillonite
3. Drab mudstone[1]	Illite	
4. Drab mudstone	Illite	Small amount of montmorillonite
5. Drab sandstone	Illite	Approximately 40 per cent of kaolinite
6. Dark green sandstone	Illite	Small amount of montmorillonite
Wind River formation		
7. Red mudstone	Illite	Small amount of montmorillonite
8. Red mudstone	Illite	Some montmorillonite
9. Brick-red mudstone	Kaolinite	
10. Red mudstone	Kaolinite	Small amount of illite
11. Drab sandstone	Kaolinite	Small amount of illite and montmorillonite
12. Drab sandstone	Illite	Approximately 45 per cent of montmorillonite
13. Drab mudstone	Illite	
"Wasatch" formation (Northern part of Bridger Basin)		
14. Red sandstone	Illite	Small amount of montmorillonite and kaolinite
15. Drab green sandstone	Illite	Small amount of montmorillonite and kaolinite
DeBeque formation		
16. Red mudstone	Kaolinite	Some illite
17. Red mudstone	Illite	Some montmorillonite
18. Drab mudstone	Illite	
Galisteo formation		
19. Red sandstone	Illite	Some montmorillonite
20. Red sandstone	Illite	
21. Red mudstone	Illite	Small amount of montmorillonite
22. Drab sandstone	Illite	
Brunswick formation		
Red-brown mudstone[2]	Illite	
Red-brown mudstone[2]	Illite	
Red-brown mudstone[2]	Illite	
Red mudstone	Illite	
Stockton formation		
Red-brown sandstone	Illite	
Chicopee shale		
Brown siltstone	Illite	
Chugwater formation		
Red sandstone	Illite	
Red sandstone	Illite	
Spearfish formation		
Red sandstone	Illite	
Chinle formation		
Red shale	Illite	
Gray shale	Illite	

[1] Analysis by R. E. Grim.
[2] Analysis by F. L. Cuthbert (1946).

(Triassic, Wyoming), and red and drab layers of the Chinle formation (Triassic, New Mexico).

CLAY MINERAL GROUPS IN SOIL AND SEDIMENTS

Microcrystalline kaolinite, montmorillonite, and illite minerals occur in soils of practically all types of climate, and each seems to have formed from various kinds of parent-rock (Kelley, 1942, p. 313). Nevertheless, only kaolinite and montmorillonite are commonly developed by soil-forming processes. Kaolinite is generally the product of deep and thorough weathering, present in well leached lateritic soils formed in humid tropical and subtropical environments, whereas montmorillonite is a product of less intense weathering in a drier or cooler climate. However, "climate and plant ecology are not the all-prevailing factors for soil formation, as now assumed by most pedologists" (Ross and Hendricks, 1945, p. 64); it is not possible at present to trace the clay minerals in soils to specific parent-rocks or to specific conditions of weathering (Kelley, 1942, p. 315).

The mode of formation of illite is not known with certainty, but at least three possible ways may exist: weathering of feldspar, disintegration of muscovite, and alteration of montmorillonite (Nagelschmidt and Hicks, 1943, p. 302).

Although the development of illite in soils appears to be favored by dry-soil regimes resulting from aridity or low temperature (Ross and Hendricks, 1945, p. 60), illite apparently does not ordinarily form there. In most analyzed mudstone and shale, on the contrary, illite is the predominant clay mineral. Here its common mode of origin probably is the alteration of montmorillonite and possibly kaolinite by diagenetic processes (Ross, 1945, p. 182), although it may also be inherited from illite-bearing source material. Because most soils developed on sedimentary rocks inherit some of their clay minerals from the parent formations, particularly under conditions of restricted weathering, those soils derived from fine-grained sedimentary rocks commonly contain abundant illite.

The clay mineral composition of sediments is determined largely by the nature of the source material and the conditions of the environment of deposition, such as alkalinity of the water, the character of the dissolved salts, the temperature, the rate of accumulation, and the kind and amount of organic material present (Grim, 1947, p. 1943).

CONCLUSION

Chemical analyses of red and drab sedimentary rocks reveal only the amount of ferric and ferrous oxide in the sample. They yield no data about the particular iron compounds. Yet this information is necessary to an understanding of the role of iron oxides as pigments. It is doubtful, however, that the various iron oxides and hydrates in sedimentary rocks can be detected and identified by chemical methods alone. Possibly x-ray and differential thermal analyses may yield this important information, as they have in soil studies.

Differential thermal analysis has revealed that illite is the predominant clay mineral group in most samples of redbeds and variegated formations so far tested. But this information tells little about the mode of origin of the sediments. In fact, it is commonly impossible to discover how the clay minerals in alluvium have originated, from what source they were derived, or under what conditions they accumulated (Kelley, 1942, p. 316).

Paleontology of Variegated Deposits

Fossil leaves from red-banded deposits have been recovered from gray layers and lignitic shale; they are warm-temperature to subtropical types, indicating humid, lowland conditions in the intermontane basins. But, as Chaney (1940, p. 473) has cautioned, it must not be assumed that this was the only flora in the Rocky Mountain region, for forests of the lowlands contribute regularly to the fossil record, whereas upland floras are seldom preserved.

A few leaves from the base of the Willwood formation were identified by Knowlton (in Hewett, 1926, p. 41) as Fort Union species. A plant assemblage from the middle of the Willwood formation, however, is more closely related to the early Eocene Wilcox flora of the Gulf Coast according to identifications made by Erling Dorf. A small florule from the Wind River formation (Berry, 1932; Tourtelot, 1946) and a flora of 43 species from the Aycross formation (Berry, 1930, pp. 55–79; Love, 1939, pp. 70–71) have many elements in common with the Green River flora, and are riverside, palustrine, or pond-border assemblages. Nevertheless, the general facies of the Aycross plants is somewhat different from that of the Green River flora from northwestern Colorado (MacGinitie, 1941, p. 87), though it does suggest " . . . the beginning of the change toward specialization and endemism of the Green River flora" (p. 93).

Fresh-water mollusks, principally snails and unios, occur in sandstone, also in gray mudstone, but have not been reported from red layers. Analysis of some from the Aycross formation confirms evidence about the environment deduced from the associated flora (Berry, 1930, p. 60).

Fragments of crocodiles and river turtles are common in both red and drab mudstone and in channel deposits, and throughout the formations remains of fish are locally abundant, especially fragments of amiids and gar-pike scales.

Most of the collections of fossil mammals from drab Paleocene formations and a few from drab layers in variegated Paleocene and early Eocene deposits have been found concentrated in small pockets or quarries. These are forest and, in part, arboreal faunas composed chiefly of diminutive multituberculates, marsupials, insectivores, primates, and rodents. Most of the fossils from red-banded sediments, on the contrary, have been found scattered throughout the matrix, and these are principally remains of larger terrestrial ungulates and carnivores. Crocodiles, turtles, and coryphodont subungulates represent a third facies of amphibious and riparious animals. The rather consistent association of a forest fauna with drab deposits suggests that they accumulated in forest swamps and

on heavily wooded flood plains. It must be emphasized, however, that this interpretation is based on very few data. A convincing demonstration of such relationships of faunal and lithologic facies requires more detailed information concerning the distribution of the fossils in red-banded formations.[10]

Paleogeographic Interpretation

Reconstruction of environment

That the red-banded formations are principally fluviatile deposits of piedmont and valley-flat environments has been well demonstrated by studies of their primary sedimentary structures and characteristic faunas (Davis, 1900; Loomis, 1907; Matthew, 1915). Especially convincing is the association of mudstone and sandstone lenses, cross-bedded channel sands, lenses of coarse conglomerate, and an abundance of fossils of terrestrial mammals together with crocodiles and river turtles. The available evidence points to the conclusion that these sediments were eroded from peripheral uplands during an early stage of the Laramide revolution when most of the alluvial material was deposited in tectonic basins which sank rapidly enough to maintain a lowland environment. Accordingly, most of the sediments underwent only short transportation. The abundance of coarse débris at the margins of the basins indicates that the velocity of the streams must have decreased rapidly downstream, concentrating the gravel on alluvial fans and carrying the sand and mud into the basin to be deposited in stream channels and on broad flood plains. Here and there, bogs, forested swamps and open lakes prevailed for short intervals. The paucity of mudcracks may be evidence that broad mud-flats exposed to repeated desiccation were uncommon. Between sites of deposition and in areas of retarded aggradation ground-water activity produced mottled profiles of weathering and effected the formation of calcareous and iron concretions.

Osborn (1929, p. 55) regarded the conditions which prevailed during accumulation of the varicolored formations as

> . . . nearly paralleled by those now found in the flood plains of Parana, Paraguay and Uruguay Rivers, which are carrying down vast masses of gravel, sand, and clay from the mountain chains of Brazil. . . . The annual rainfall in these mountains ranges from 100 to 136 inches, and it rapidly disintegrates the yielding rocks and discharges a vast quantity of detrital matter over the broad plains of Argentina and Uruguay. The mountain streams have thus built up wide, level areas in these countries, and the lower rivers, ploughing their channels through the vast deposits over which they must make their way, extend their banks with every increment and thus continually make additions to the outskirts of the formation they are depositing.

Hewett (1926, p. 40) has suggested that in the southwestern part of the Bighorn Basin Willwood sediments were deposited on a surface of low relief.

[10] Simpson's recent study (1948, p. 381) of the San José formation in the San Juan Basin, New Mexico, shows that the hypothesis seems reasonable in general application to the broad facies of this formation.

> . . . There were undoubtedly several large streams that rose in a mountainous area farther southwest and flowed generally northeastward toward the center of the Big Horn Basin. There were also probably smaller tributaries of irregular pattern. . . . When all the sedimentary and stratigraphic features of the formation in this region are considered, it is very apparent that the coarse material represents an alluvial fan spread out on the border of an extensive alluvial plain at the point of emergence of one of the major rivers that supplied the sediments. The fan is roughly triangular and is 5 or 6 miles wide at the base and 8 or 10 miles long, with the apex at the mouth of the ancient river.

Apparently the depositional environment of the red-banded formations was similar to that of the late Cenozoic Siwalik series in the Himalayan foothills (Krynine, 1937), and of the early Cenozoic Sespe formation in southern California (Reed, 1929).

Bryan's study of the Sacramento Valley of California (1923) suggests a late Cenozoic environment there not unlike that in the Rocky Mountain intermontane basins during early Cenozoic time. Sacramento Valley is a structural depression bounded by the California Coast Ranges and the Sierra Nevada, and filled with at least 2,000 feet of unconsolidated alluvium. Its surface, mostly less than 300 feet above sea-level, is an

> aggraded plain, built up with sediments brought by the streams from the surrounding mountains. For a long time the valley has been sinking and the bordering mountains have been rising. With the uplift of the mountains erosion increased and the streams carried much sediment. . . . The present configuration of the plain is due largely to the forms produced by deposition of sediments (Bryan, 1923, p. 9).

The master streams are characterized by intricate meanders, sloughs, and natural levees which slope gently toward the swampy flood basins and ox bow lakes or toward adjacent alluvial plains. In time of flood, the low areas of the flood plains are filled by the side streams that pour across the alluvial plains in broad sheets and by the rivers which discharge into them either through definite channels or over natural levees. In the swampy flood basins heavy blue clay is accumulating, for these basins, like the alluvial plains and natural levees, "are the result of processes of deposition that are still active, but the deposition is essentially that resulting from standing water, rather than running water, and hence their surfaces are almost horizontal planes" (Bryan, 1923, p. 10).

RATE OF ACCUMULATION

An estimate of the rate of accumulation of Willwood deposits in the Bighorn Basin, calculated for a source area of about 7,800 square miles yielding sediments that were distributed over a basin of about 6,500 square miles (for method see Bradley, 1930, p. 108), agrees with Bradley's figure of 1 foot in 3,000 years for the rate of accumulation of the "Wasatch" formation in southwestern Wyoming. But this is a far slower rate than Schuchert's estimate (1931, p. 13) of 1 foot of sandstone in 450 years and 1 foot of shale in 900. On the basis of a varve analysis of middle Cenozoic sediments deposited in the Burmese Gulf, Stamp (1925) estimated that

. . . a comparatively fine-grained sand may have been piled up at a rate of a foot in twenty-five years, whilst numerous calculations as to the rate of deposition of alternating sands and clays gives an average round about a foot in sixty years. Even a homogeneous clay may be laid down as rapidly as a foot in 200 years or even less (p. 528).

Gillette (1938, p. 167) believes that 120 years to the foot of rock is the average suggested by studies of varved deposits. Although these figures reveal all too clearly the lack of definite information concerning the rate of accumulation of sediments, they do give an estimate of the length of time involved in the deposition of a layer of mudstone. Apparently the factors controlling the deposition of a red or drab stratum may have persisted for several hundred, or perhaps even several thousand years.

EARLY CENOZOIC CLIMATE

A persistent view encountered in geologic publications (see Atwood and Atwood, 1938, p. 962; Osborn, 1929, p. 51; Grabau, 1914, p. 629) holds that in the early stages of the Laramide revolution (late Cretaceous to early Cenozoic) the Rocky Mountains were elevated to great heights. But great mountain ranges would have produced arid conditions in the basins on the east, for Chaney (1940, p. 486) has shown that the major wind currents in early Cenozoic time were essentially as they are to-day. It is significant, therefore, that no such climatic change is reflected in the paleontologic record. Dorf (1942, p. 101) has interpreted the Lance (late Cretaceous) flora as indicating warm-temperate to subtropical climate. The Paleocene Raton flora yields no evidence of physical or climatic change from warm and humid late Cretaceous Vermejo conditions (Knowlton, 1917, p. 240). Moreover, Knowlton's comparison of Laramie, Denver, Raton, and Wilcox assemblages (1930, p. 12) suggests all were warm-temperate and possibly subtropical; hence, the Paleocene climate was little changed from antecedent Cretaceous conditions. (See Dorf, 1942, pp. 111–23 for analyses of these floras.) Early and middle Eocene floras from the Rocky Mountain region are also lowland, warm-temperate to subtropical types, evincing no important climatic change from Paleocene time (see also Berry in Osborn, 1929, p. 65; Seward, 1933, p. 432); and the mammalian fauna in no way contradicts this record. Chaney (1936, Fig. 1A) shows the early Cenozoic subtropical forest "extending from central California north into Washington, eastward into Montana, and south to New Mexico." The principal differences among these early Cenozoic floras probably are due to differences in latitude, although MacGinitie (1941, p. 79) believes that in the Pacific Coast states there is evidence of a northward migration of subtropical plants during early Cenozoic time due to a general temperature increase which apparently culminated in the latest Eocene or earliest Oligocene time.

After this began the swing to the cooler and drier conditions of the late Tertiary. This is in harmony with the observations made by Berry concerning the climatic tendency indicated by the early Tertiary floras of the southeastern states. . . .

Such an interpretation is consistent with Chaney's reconstruction of the early Cenozoic environment in the Rocky Mountain region (1940, pp. 476–86; see also Clement and Chaney, 1936, pp. 7–10, 19), and with Brooks' conclusion (1926, pp. 47–95) that during early Cenozoic time the subtropical high pressure belt was north of its present position so that mild, subtropical climate prevailed over most of what are now temperate regions. Brooks believes (p. 63) that within the subtropical belt much of the land was under the influence of a mediterranean type of climate with a moderate winter rainfall and a long, dry, hot summer. MacGinitie, on the other hand, believes (1941, pp. 72–78) that the early Cenozoic climate of the west, though subtropical with alternating wet and dry seasons, had a pronounced summer maximum of rainfall.

EFFECT OF LARAMIDE REVOLUTION

The climatic interpretation accords with a view that the Laramide revolution was not a brief orogenic episode that produced an abrupt change in the topography of the Rocky Mountain region. Instead, intense Laramide deformation began in late Cretaceous time and continued into the Cenozoic. The persistence of a humid, lowland environment during this interval of orogeny suggests that the basins were downwarped as the basin-fill accumulated, and that either the deformation of the peripheral uplands took place without great upward movement or erosion kept pace with orogenic uplift and maintained a mature stage of topography. The basin floor probably was not more than 1,000 feet above sea-level, with peripheral mountains rising several thousand feet above this surface (Bradley, 1930, p. 89).

Mackin's study (1937) of the geomorphic history of the Bighorn Basin led him to conclude that the present height of the Rocky Mountains is a culmination of uplift throughout the Cenozoic era and that the region is still in a first cycle of erosion. The increasing coarseness and progressive eastward distribution of Cenozoic sediments and the sequence of floras from the Rocky Mountain region corroborate this interpretation (Clement and Chaney, 1936; Chaney, 1940). The earliest indication of the trend probably is found in a comparison of Paleocene and Late Eocene floras, which reveals a change from dominantly subtropical plants to an increasing number of temperate ones. Early Eocene mammals show a perceptible increase in ungulate forms—the beginning of an expansion of cursorial plains-dwellers that continued throughout later Cenozoic time. It is reasonable to expect that the sedimentary record also reflects this changing environment.

During the early stage of the transition from heavily forested lowlands of early Cenozoic time to widespread grasslands of the later Cenozoic when cursorial mammals were predominant, a red-banded sedimentary facies accumulated in intermontane basins and its mammalian fauna suggests savanna conditions of forests and open parks. According to this interpretation an environment peculiar to the transition period may have been the controlling factor in the production of the red-banded facies.

INTERPRETATION OF GREEN RIVER FORMATION

Lacustrine sediments are associated with some variegated fluviatile deposits, indicating that occasionally one facies gave way to the other. In southwestern Wyoming the upper part of the red-banded "Wasatch" formation was deposited at the margin of the Green River Basin while Green River lake beds accumulated at the center. A brief extension of fluviatile conditions spread red-banded sediments over the lake deposits and as a result the marginal part of the lower Green River formation is covered by the variegated Cathedral Bluffs tongue of the "Wasatch" formation. When the lake expanded again deposition of the varicolored facies was limited to the basin's margin.

In the Bighorn Basin the red-banded Willwood formation is overlain by the Tatman lake beds. A lens of red and gray mudstone within these lacustrine deposits suggests a temporary return of fluviatile conditions. The varicolored North Horn formation in central Utah (Spieker, 1946, p. 122) contains local layers of marlstone. Above the North Horn is the extensive Flagstaff limestone, and above that the red and drab Colton formation which, in turn, is overlain by the Green River lake deposits, indicating a close relationship of fluviatile and lacustrine facies.

Evidence adduced from a study of these lacustrine deposits has an important bearing on the problem of the origin of the associated red-banded sediments, particularly because the flora from some variegated formations is similar to that from the Green River.

The environment indicated by the Green River flora has been compared with that between South Carolina and Louisiana (Berry, 1930, p. 58) and that of the south slope of the Mexican Plateau (Chaney, 1944, p. 523).

> Of such an environment as I have conjured up for the Green River flora there is perhaps no exact duplicate on earth today, but the climate conditions of the southeastern Gulf states plus those of part of the Great Valley of California, would, it seems to me, roughly approximate those of the Green River lake area (Brown, 1929, p. 281).

Bradley's detailed study of the Green River formation led to the conclusion (1930, pp. 91–118) that the climate was a mediterranean type, characterized by a mean annual temperature of 65°F. and by seasonal rainfall with a mean annual precipitation between 30 and 43 inches.

In contrast to the subtropical flora represented by the fossil leaves, the Green River pollen record (Wodehouse, 1933, pp. 518–21) reveals a flora similar to that of the middle and northern Atlantic states to-day, suggesting a more temperate climate in the well watered uplands surrounding the lake basins.

MacGinitie (1941, pp. 87–94) has emphasized the rather specialized, endemic character of the younger Green River flora, and interprets it as having flourished in enclosed basins during the onset of "less favorable upland or continental conditions" accompanied by dry periods. It should be noted, however, that the Eocene floras with which the Green River assemblage has been compared "were all coastal in distribution. . . . By contrast the Green River flora lived in the interior where the climate was of a continental type" (Chaney, 1944, p. 521).

Even though the presence of cactus suggests a climate with marked dry seasons, there is ample evidence of extensive forest swamps.

Recurrent groups of exceptionally thick varves in the Green River formation, indicating intervals ranging from 7 to 18 years, are suggestive evidence of the effect of the 11-year sun-spot cycle.

Cyclic changes in the conditions of sedimentation of approximately the same average period as the resultant of the change of eccentricity of the earth's orbit and the precession of the equinoxes are indicated by a regular alternation of beds of oil shale and organic marlstone (Bradley, 1930, p. 105).

The average interval is 21,600 years and agrees with the 21,000-year precession cycle as modified by the cyclic change in the position of the major axis of the eccentricity of the earth's orbit.

If a distinct but yet not abnormally large eccentricity of the earth's orbit is assumed, the precession of the equinoxes should have produced during one-half of its cycle a climate in which the summers were short and hot and the winters were long and relatively cool and in the other half of the cycle a climate in which the winters were short and mild and the summers long and relatively warm. The mean annual temperature would have remained about the same, however, and the principal difference of climate in the two parts of the cycle would have been in the seasonal distribution of temperature (Bradley, 1930, p. 106).

Other cycles of 23 and 50 years have also been recognized in the Green River deposits (Bradley, 1938).

Part II. Introduction

In any attempt to determine the origin of ancient sediments it is especially important to correlate evidence from several sources because no one line of inquiry yields data which are in themselves unequivocal evidence. The reliability of the paleogeographic reconstruction will depend largely on the number of data assembled as well as on a correct interpretation of them.

In such a study of the origin of red-banded sediments one must know whether the source material which was carried into the basins was principally disintegrated, undecomposed fragments of bedrock of the mountains, or whether it was mainly soil washed from the uplands.

No consideration of the sources of terrigenous sediments is complete if soils are omitted, as in many, and perhaps in most cases, sediments are not derived directly from rocks, but from the products of decomposition, which as soils mantle the surface to greater or less thickness (Twenhofel, 1939, p. 145).

Studies of soil erosion (Bennett, 1939, pp. 92–94, 122–23, 194; Kellogg, 1941, pp. 76–77; Robinson, 1936, pp. 67–69) show clearly that, excepting on very steep slopes, the protective covering of vegetation in a warm humid climate tends to retard erosion, especially where the rainfall is uniformily distributed throughout the year, so that soil develops from fresh rock below nearly as fast as normal erosion carries it away. Generally, under natural conditions a balance is maintained between soil-forming and soil-eroding forces, the waste-mantle being removed

by soil creep and slumping, and by sheet and gully erosion. With seasonally distributed rainfall and considerable relief, the surface run-off may break through the vegetation cover, incise deep canyons, undercut the valley walls, and remove both soil and disintegrated bedrock.

This normal erosion is not to be confused with accelerated soil erosion brought about by human disturbance of the natural equilibrium between soil-building and soil-removal. Yet even in such dissected uplands as the cultivated piedmont region of southeastern United States and the slopes of the Hawaiian Islands, a thick mantle of decomposed rock is maintained in spite of the accelerated erosion.

Climate is another significant aspect of the environment controlling the nature of terrestrial deposits, particularly because climatic changes are widespread in their influences and the effects are quickly felt. Altered climates do not ordinarily migrate slowly from region to region, but rather the results are simultaneous over large areas (Blackwelder, 1918, pp. 163–64). Climatic types referred to herein are those formulated by Köppen, as defined by Trewartha (1943). In delimiting climate groups, factors of humidity type and the associated native vegetation, seasonal distribution of rainfall and particularly the rainfall during the wet season, and mean annual temperature are significant. Humidity types of arid, semiarid, and humid climates must be carefully differentiated on the basis of the amount of rainfall and its seasonal distribution, the amount of soil moisture, and the prevailing temperature (Krynine, 1947).

Even though the red and drab lenses are of limited extent, it does not necessarily follow that the factors controlling their color had the same limited distribution. By the very nature of flood-plain deposition alluvium accumulates only along stream courses. Hence, at any one time, factors affecting the color of the sediments might have prevailed over an entire basin area, yet would be reflected only locally in the lenticular alluvial deposits. Such a relationship is in contrast to the correlation between climatic change and accumulation in a lacustrine environment, for example, where variation in conditions over the entire area would alter the character of the sediments accumulating throughout the lake basin.

Although the red color of the sediments is seemingly the peculiar feature to be accounted for, any hypothesis proposed to explain its origin must necessarily also account for the color of the drab deposits. The similarities between the drab layers and the thick drab sandstone and mudstone formations of late Cretaceous and Paleocene age suggests a similar origin. Yet, a real difficulty is the lack of information concerning the factors controlling the origin of the drab formations. Studies of these Cretaceous and Paleocene formations indicate that they are piedmont, valley-flat deposits, commonly containing extensive beds of coal. Hence, it is a pertinent observation that

> . . . on flood plains having an abundance of vegetation it makes little difference what were the colors of the sediments at the times they were deposited, as any contained iron oxide is certain to be reduced [by incorporated organic matter] and the sediments given gray and perhaps dark colors (Twenhofel, 1932, p. 807).

The problem of the origin of red-banded deposits probably can not be solved by the direct method of induction alone, for the appropriate inferences drawn from the chemical and thermal analyses, the paleontological data, and the observed stratigraphic relationships are not sufficient to explain the origin of the sediments. Instead, the solution depends on the invention and testing of several hypotheses. From the postulated modes of origin, consequences have been deduced which ought to follow, and these have been investigated in light of the observed facts and of studies of modern climates and soils.

With the assumption that the red and drab layers in varicolored formations are the result of different conditions of origin, the following, in outline, are suggested modes of origin of the color of the red lenses.

SYNOPSIS OF POSTULATED MODES OF ORIGIN

Mode	*Climate*	*Process*
A. Red pigment developed at place of deposition	1. Warm, humid	Development of red soil
	2. Warm, arid, or semiarid	Concentration of hydrated ferric oxide during and after deposition, subsequently dehydrated
B. Red pigment derived from source area	3. Indifferent	Erosion of red bedrock
	4. Warm, seasonally humid	Erosion of red soil

HYPOTHESES OF RED PIGMENT DEVELOPED AT THE PLACE OF DEPOSITION

IN WARM HUMID CLIMATE

If it is inferred that the color of variegated sediments was developed at the place of deposition, one might hold that the same processes that now produce red soils in warm, moist climates should have produced red soil on flood plains in the intermontane basins when the climate was warm and humid. But there is no evidence to support such an interpretation. Careful distinction must be made between the effects of a well drained upland and a poorly drained lowland region of alluviation, for a saturated flood plain is not favorable for the development of red soil. Any soil that does form probably would be "alluvial soil," showing little or no modification excepting a slight accumulation of organic matter in the surface (Kellogg, 1941, p. 340). As a result of continual aggradation there is little chance for development of a soil profile, hence the characters of the alluvial soil are determined largely by the nature of the materials from which they have been derived and the manner in which these materials have been sorted and deposited (Ableiter and others, 1938, p. 1133).

Furthermore, if red pigment was developed at the place of deposition under warm, moist conditions, it would follow that drab color resulted from a different

climate. But this is not the case, for coal beds in thick drab formations and lignitic layers associated with drab lenses of the varicolored formations clearly indicate a warm, moist environment.

IN WARM, ARID, OR SEMIARID CLIMATE

The color of Paleozoic and Mesozoic redbeds, as well as the color of the red layers in variegated deposits, has been attributed by many authors to chemical changes during and after deposition under semi-arid or arid conditions. Such an inference arises from the rather common assumption that some unusual cause of oxidation is required to produce hematite in sediments, but the oxide once formed will necessarily color the sediment red. That this is an oversimplification of the role of the ferric oxides as pigments has already been pointed out.

The view frequently expressed in earlier studies (Crosby, 1891; Barrell, 1908) is also based on the now discredited belief that hematite may be derived from yellow to brown hydrated oxide by virtually spontaneous dehydration by exposure to warm air.

> While red in present soils is particularly characteristic of the residual soils of warm moist climates, in ancient deposits it is a usual accompaniment of arid conditions (Barrell, 1908, p. 291).

Barrell had observed that "red shading into brown" is one of the most common colors of ancient continental deposits, and that many of the redbeds were of fluviatile origin. But he had discovered that alluvium of many modern streams is yellow or brown, even when derived from red soil. For this reason he concluded (see also Miller, 1910; Alling, 1928) that dehydration of limonite was a necessary factor in accounting for the great predominance of red color in " . . . ancient ferruginous formations and the comparative absence of yellow tones such as dominate modern alluvium" (p. 286). Even though it has been demonstrated that such a process of dehydration probably is not an important factor in the origin of red sediments, this does not vitiate the significance of Barrell's observation of the discrepancy between the yellow color of alluvium to-day and the red color of many ancient fluviatile deposits. This relationship must be explained satisfactorily by any proposal.

Inasmuch as most geographical and geological studies have been made in temperate regions, the inference that modern streams deposit yellow alluvium is based on incomplete evidence. More detailed descriptions of the tropics are needed, for, as Barrell (1908, p. 163) had noted, there the alluvium of many large rivers is red. Moreover, many of the particular environments of the past may not be in effect to-day, so that no present situation is quite similar to the conditions under which many red deposits accumulated in the past. Perhaps, as Raymond (1942, p. 660) puts it in his discussion of the origin of redbeds, " . . . we are leaning a little too heavily on the principle of uniformitarianism." In many cases, detailed study of ancient sedimentary rocks is the only source of information con-

cerning certain peculiar sediments which, so far as known, are not being formed extensively at the present time.

Barrell's solution, on the other hand, presents a difficulty as critical as the one he attempted to eliminate, for to maintain that red deposits result from dehydration of yellow alluvium is to imply that there should be few ancient yellow deposits.

Other criticisms of this possible mode of origin of red pigment have been summarized by Tomlinson (1916, pp. 163–67, 173–77), Raymond (1927, pp. 239–40), and Krynine (1947). These authors have shown that the red color of a formation is no function of its geologic age for there are geologically old and young redbeds, and that the redness of a formations bears no apparent relation to depth of burial. Moreover, whatever part time and heat play in producing red color, these agents are more effective in a warm, moist climate.

The presence of red soils in deserts has been cited as supporting the conclusion that the pigment in red sediments developed at the place of deposition under arid conditions. Actually less than 5 per cent of red soils forming to-day are found in regions which at the present time have a rainfall of less than 40 inches (Krynine, 1947). Much more commonly gray colors predominate as desert soils. (See also Boswell, 1940, p. 253.)

Of the small percentage of red soils found in arid regions some have formed in place as a thin reddish brown surface soil with brownish red or red subsoil, showing much physical weathering, very little leaching, and only slight laterization (Kellogg, 1941, p. 330; Ableiter and others, 1938, pp. 971, 1100–01). Other red desert soils appear to have inherited their pigment from older red sediments or to have been formed in older, more humid climates. In the semiarid Bighorn Basin red soil now develops only on Triassic redbeds; most of the basin's surface is covered by gray-brown desert soil (Thorp, *et al.*, 1933, p. 37). The San Joaquin soil of the Great Valley of California has been described as a red desert soil, but it may be "the product of development under a former and different climatic environment from that now prevailing in the region" (Marbut, 1935, p. 93). In fact, the coincident distribution of the red San Joaquin soil (Marbut, 1935, Pl. 5, sec. 5) and the red older alluvium of the Sacramento Valley (Bryan, 1923, Pl. III) suggests that the red pigment of the soil in the northern half of the Great Valley may have been inherited from the older alluvium which had been washed from the Sierra uplands in late Pliocene or Pleistocene time.

In 1907 Loomis presented an analysis of the red-banded formation in the Bighorn Basin which showed clearly the fluviatile nature of the sediments. In postulating the conditions of origin (p. 361) he concluded that

> the red bands are due to the alluvial deposits being exposed to the sun, the vegetation cover being scantier and the effects of the heat greater. . . . Where little organic matter is present, the hydrated oxide, limonite, makes the sandstones and shales cream and brown color; however, when exposed to air, if under dry and hot conditions, the limonite is reduced to hematite, the color then changing to red.

Sinclair and Granger (1911, pp. 115–17) amplified this interpretation. They maintained that the red color in variegated sediments is due to "the introduction of iron compounds [into drab mud] in solution and their concentration and oxidation possible under dryer climatic conditions than existed during the deposition of the blue clays." Accordingly, the red coloring was a local feature, essentially the result of conditions of deposition. The red color of the beds in the variegated Puerco and Torrejon formations[11] was also attributed to dehydration on drying (Sinclair and Granger, 1914, pp. 309–10). That the color was not the result of simple oxidation and dehydration of drab mud after deposition follows from the greater amount of total iron in red layers (Table II) and from the observation that drab mudstone is not changed to red in the present semiarid climate. Instead, it weathers to a buff color. Hence, Sinclair and Granger concluded that an excess of about 1.5 per cent Fe_2O_3 in the red layers was introduced into drab mud at the time of deposition in a dry climate. Their inference, that the process was effective only during deposition as the sediments accumulated locally on flood plains, was necessary to account for the interfingering of the variegated beds. If the pigment had been introduced after deposition the sediments on the entire surface of the basin would have been colored red during each dry period. Association of drab strata and lignite layers was interpreted as indicating preservation of drab color during humid periods, while red mudstone was thought to have formed during drier periods when decaying plant débris was completely oxidized.

The postulated accretion of excess iron in red layers during dry periods implies that hematite is concentrated more readily in a dry climate than in a moist climate. In desert regions iron may be introduced into sediments, coloring them red or yellow (Twenhofel, 1939, p. 58). But such a process would probably be more effective in sandstone than in relatively impervious mudstone. Under arid conditions

> . . . the water is evaporated at or near the surface, and the sands may be stained by the oxidation of the dissolved iron thus precipitated. Instances of this sort are, however, rare (Raymond, 1927, p. 238).

That this is an uncommon activity of ground water is confirmed by Polynov's review (1937, pp. 98–113) of the fate of iron compounds during weathering, which emphasizes the importance of abundant moisture and of ground-water solution. Similarly, Moore and Maynard (1929, p. 277) observe that the iron in some of the large sedimentary iron formations was transported principally as a ferric oxide hydrosol, stabilized by organic matter in a colloidal state, the iron either being transported as a colloid or adsorbed by organic colloids. In the tropics many soils are actually enriched in Fe_2O_3 by precipitation and coagulation, whereas in profiles in semiarid regions there is little migration of iron, and under desert conditions, where chemical weathering is generally at a minimum, there is incomplete leaching and less liberation of Fe_2O_3 (Robinson, 1936, p. 47).

Sinclair and Granger (1911, p. 113) regarded the presence of arkose in varie-

[11] San Juan Basin, New Mexico.

gated deposits as good evidence of a dry climate with rapid changes of temperature—an interpretation which appears frequently in geological publications. But ample data now indicate that arkose forms almost independent of climate. In humid regions it accumulates under conditions of deep dissection of granite and rapid transportation and burial of the débris, with a minimum of reworking (Hatch and Rastall, 1938, pp. 99–100; Krynine, 1936a, p. 87).

Fragmentary and scattered mammalian remains in red layers were cited as evidence of weathering under dry conditions before burial, and associated skeletal material in drab layers was supposed to indicate rapid burial under humid conditions (Sinclair and Granger, 1911, pp. 116–17). It is doubtful, however, that the differences of completeness of the fossils are distinct enough to aid in interpreting the climate.

Nor are gypsum fragments scattered on badland slopes evidence of aridity during deposition of the variegated sediments. Similar occurrences of gypsum found in many places on drab Polecat Bench[12] (Paleocene) outcrops and associated with lignite layers in the Tatman formation[12] are probably the result of groundwater activity in the present arid cycle.

Although Sinclair and Granger postulated an alternation of moist and dry conditions they found no evidence of excessive aridity, for the mammalian faunas of the red and drab beds are similar. Ignoring this caution, Grabau (1913, p. 629) extended the interpretation to imply considerable aridity, stating that

> these Tertiary deposits on the eastern slopes of the Rockies have thus all the characteristics of deposits formed under semiarid conditions. These conditions prevail today in the region under the influence of the westerly winds, which, on crossing the Coast Range, where they leave most of their moisture, become still drier on crossing the Rockies. Greater elevation of the mountain ranges would probably increase the aridity of the intermont basins in this region and so establish the conditions of Tertiary time.

A review of the pertinent floras has shown that there is no evidence to support such an interpretation of early Cenozoic climate and topography.

In summary, the hypothesis of the origin of red pigment in a warm, dry climate errs in attributing the color to dehydration of hydrated oxides, and is incomplete because it does not account for the nature of the sediments carried into the basins to form the drab and the red layers. If dry periods were involved, the aridity more probably aided in preserving, not in producing, red pigment.

Hypotheses of Red Pigment Derived from Source Area

Introduction

Two hypotheses deriving the pigment from red source material, either from older redbeds or from red upland soil, are alike in that each implies that the hematite was transported into the basins along with the clastic sediments it colors, and each presents a similar problem of accounting for the preservation or alteration of the color at the place of deposition.

[12] Bighorn Basin, Wyoming.

BY EROSION OF RED BEDROCK

The earliest interpretation of the origin of the variegated deposits was formulated by Hayden (Meek and Hayden, 1862, pp. 433–34), Peale (1879, p. 636), and Wortman (1882, pp. 140–44) who suggested that the red layers might have been derived from "Juro-Triassic red beds" at the borders of the basins.

Taylor (1932) developed the hypothesis in considerable detail as an explanation of the origin of the Wind River formation,[13] and Stagner (1941) has presented a similar interpretation of the origin of the red layers in the Uinta B formation.[14]

Some red formations, such as the Jurassic redbeds of Nevada and Utah, probably are second-cycle products of erosion of older red rocks, deposited in an arid or semiarid environment (Krynine, 1938, p. 96). Such an interpretation of the origin of the red lenses in variegated formations may seem to follow from the fact that red Triassic rocks crop out in the foothills around most of the basins, and that the early Cenozoic basin-fill was eroded from the peripheral uplands. Nevertheless, a review of selected stratigraphic data suggests that there is no necessary connection between redbed outcrops and red lenses in the early Cenozoic formations.

The evidence that pre-Cambrian rocks of the mountain cores around the Bighorn Basin were eroded during Paleocene time implies that the red Chugwater formation flanking the uplifts was also eroded by streams flowing into the basin. Yet there are very few red layers in the drab Polecat Bench formation.

Extension of some of the red-banded formations marginward so that they overlap Mesozoic redbed formations and rest on rocks as old as pre-Cambrian suggests that locally variegated sediments accumulated after Triassic and older rocks had been stripped from the Laramide uplifts (Bartram, 1939; Heaton, 1937) and their outcrops buried beneath the basin-fill.

The indications that red-banded sediments accumulated when pre-Cambrian, Paleozoic, and Mesozoic rocks were exposed in the source areas and when all but pre-Cambrian outcrops were buried, and that few red lenses formed at times when red Triassic rocks were exposed, lead to the inference that accumulation of red-banded fluviatile deposits was dependent on factors other than erosion of Triassic redbeds.

Thin layers of red sediment derived from Chugwater outcrops are present in the alluvium of the Bighorn River near the southern margin of the Bighorn Basin. During storms, intermittent streams flowing from the north flank of the Owl Creek Mountains spread a thin veneer of red mud over the Bighorn flood plain. Each layer is a few inches thick and the contact between the red mud and the drab flood-plain alluvium is an abrupt change of color and grain size.

Taylor (1932) thought that this observation revealed the mode of origin of the variegated early Cenozoic deposits. But such an interpretation probably is fallacious. On the basis of available evidence of rates of deposition, most of the

[13] Wind River Basin, Wyoming.

[14] Uinta Basin, Utah.

fine-grained red layers in varicolored formations are too thick to have been deposited during a single period of flood. Even though estimates of the rate of accumulation of flood-plain deposits vary widely, the data suggest that a period measured in at least tens, and possibly hundreds of years is required for the deposition of one foot of sediment in a warm, humid region, where erosion and subsequent alluviation generally are more rapid than in an arid one (Barrell, 1908, p. 189; Krynine, 1947).

Moreover, accumulation of thin red layers on the present Bighorn flood plain depends on a change of source material and stream velocity in flood time. Variegated mudstone layers, on the contrary, are indistinguishable in most characteristics other than color; the red and drab lenses have a similar range in grain-size and seldom are separated by sharp contacts. Hence, there is no reason to suppose, as one must if postulating a Chugwater origin of the red mudstone, that the red layers in variegated formations accumulated during periods of increased stream velocity.

Taylor's study is an attempt to discover the origin of varicolored early Cenozoic sediments that accumulated in an aggrading, humid, subtropical lowland by observing the activity of degrading streams in semiarid, upland basins. Clearly, the problem of the origin of red-banded deposits needs study in an environment comparable with that of the Rocky Mountains in early Cenozoic time, such as the Sacramento Valley of California and the Maracaibo Basin of Venezuela.

In summary, the hypothesis of derivation of red pigment by erosion of red bedrock, as a general explanation, is not confirmed by the available field evidence. There is no discernible relationship between the exposure of Triassic redbeds and the accumulation of variegated deposits; nor are the conditions under which red formations in the Rocky Mountain region yield red alluvium to-day comparable with conditions which produced the early Cenozoic formations. Nevertheless, redbeds may have locally supplied the pigment of some red layers in the varicolored deposits. Stagner (1941), for example, believes that the sediments of red layers in the Uinta B formation were derived from older red formations north of the Uinta Basin, whereas the drab material was derived from an eastern source. Where the two drainage systems joined there was a mingling and interfingering of red and drab sediments.

BY EROSION OF RED SOIL

Redbed studies.—The pigment of most typical redbeds is generally believed to be hematite developed in the regolith of the source area and transported and deposited as a clastic sediment in an extremely fine state of subdivision. Russell (1889), Tomlinson (1916), and Krynine (1947) have reviewed the differing opinions and conflicting evidence as to the origin of redbeds, and have concluded that red soils formed under a warm, moist climate were the source of the coloring matter and of much of the clastic material in redbeds.

Present knowledge concerning the ferric oxides and hydrated ferric oxides

favors this interpretation, and Raymond (1942) has adduced supporting data from recent soil studies. The extensive development of red soils to-day, together with numerous examples in the geologic record, is so common that the term rubification has been proposed for the process (Bryan and Albritton, 1943).

Primary, pre-depositional redbed source material probably developed in a warm, humid environment much like that of the southern Appalachians to-day or of the western slope of the Sierra-Cascade upland where red and yellow soils showing the effect of laterization have formed on all kinds of bedrock. In these soils kaolinite ordinarily is the predominant clay mineral. Red soil is especially characteristic of well drained uplands, and its formation appears to be favored by an alternation of moist and dry seasons (Kellogg, 1941, p. 187; Robinson, 1936, pp. 312–14) because alternate wetting and drying apparently leads to more rapid decomposition than does constant humidity.

From this interpretation it would logically follow that the predominant clay mineral in red alluvium should be of the kaolinite group. Instead, illite is predominant in ten samples of redbed formations (Table III). There are two possible explanations of the presence of the illite: (1) kaolinite or montmorillonite developed in the source area may have been altered to illite after deposition, and (2) illite inherited by the upland soils from older sedimentary rocks may have persisted in the derived alluvium. Present information concerning the fate of transported clay minerals is too meager to permit choosing between these alternatives. In view of other supporting evidence, however, the red soil source of redbeds appears to be a valid hypothesis.

Humid tropical and subtropical environments.—Evidence that the early Cenozoic climate in the Rocky Mountain region was warm-temperate to subtropical, that extensive red regolith develops in uplands in such an environment, and that a waste-mantle of red residual soil probably was the source of a great part of redbed sediments, makes detailed observations of environmental conditions in humid tropical and subtropical regions particularly relevant (Cotton, 1942, pp. 90–100; Krynine, 1936b; Robinson, 1936, pp. 311–31).

Humid tropical climate is characterized by a mean annual temperature of about 68–80°F., a temperature of 64°F. or higher during the coolest month, and at least 50 inches, and often more than 80 inches, of rainfall a year. Such a climate is generally limited to regions from sea-level to 3,500 feet in altitude. Humid subtropical climate (including warm-temperate of some authors) has an average temperature of 34°F. or more during the coolest month and 72°F. or more during the warmest month. Average annual precipitation is 40–60 inches.

In humid tropics and subtropics the rainfall commonly assumes an annual or semiannual maximum, at which time precipitation occurs in heavy downpours. Depending on the sharpness of this periodicity and the length of the dry season (winter), humid tropics are of two kinds: (1) the constantly humid tropics—the climate of the permanently humid rainforests and the rainy monsoon regions; and (2) " . . . the seasonally humid tropics, which embrace regions with a savanna

climate characterized by a marked dry season and a more open and parklike arrangement of vegetation. The absolute precipitation on such a savanna may, however, be extremely high" (Krynine, 1936b, p. 299). Although the average annual temperature is nearly the same as in the constantly humid tropics, the seasonal range is greater. The savannas of Central America, the veld of southern Africa, the campos of Brazil and llanos of Venezuela, and the highland of the Cameroons are examples of seasonally humid tropics. The subtropical climate of southeastern United States (sometimes called warm-temperate east coast climate) with its warm moist summers and cooler, drier winters, is also seasonally humid (White and Foscue, 1943, pp. 10–11; Robinson, 1936, p. 322).

In tropical rainforests, deep chemical decay and vertical erosion commonly acting on bedrock in steep canyons, are important factors of both sedimentation and land-sculpture. Rapid decomposition leads to the development of deeply weathered soils. But the dense vegetation retards soil creek and rainwash, and restricts lateral corrasion of the streams. Nevertheless, the considerable run-off which occurs because the soil is near its saturation point leads to gullying and deep vertical dissection. The cutting of steep canyons is accompanied by slumping and landslides, and by the erosion of bedrock which may yield arkose. With rapid burial on alluvial fans such débris is preserved from chemical decay (Krynine, 1936a, p. 87). Only in an advanced stage of regional degradation, with decreased relief, do soil creep, rainwash, and lateral corrasion remove much regolith.

In the seasonally humid tropics and subtropics with less dense vegetation, saturation of the regolith by heavy rains during cloudbursts and downpours leads to sheet erosion which strips away red soil. Landsliding on steep-walled valleys also aids in bringing the waste-mantle to the streams. Because of the suddenness of the storms, streams are subject to considerable fluctuation, and in deep canyons they may cut into bedrock. During the wet season leaching by percolating waters may occur, but during the rather long dry season evaporation becomes effective and the soil may be dried out to a considerable depth, and chemical decay retarded.

Closely related to seasonally humid subtropical climate is the mediterranean subtropical climate of the Mediterranean region and of central California. This is a winter rain climate, characterized by dry summers having an average temperature of 70–80°F. and moist winters having an average temperature of 40–50°F. Generally there is less rainfall than in humid subtropics; hence, grasslands are more extensive than forests.

Depositional environment of redbeds.—Although it is now generally agreed that red soils were the source of many red formations, there is less agreement as to the environment in which the redbeds accumulated, for red color alone is not evidence of the environment at the place of deposition. Yet upon an interpretation of the paleogeography rests the solution of the origin of not only the red layers in varicolored deposits, but the drab layers as well.

Most redbeds apparently were flood-plain deposits that accumulated rapidly

enough to preserve the color, or in a climate less humid than that in the source area. According to either inference, persistence of the red color after deposition depends primarily on non-reducing conditions.

Raymond (1927, pp. 244–46; 1942, p. 668) believes that the significance of red color in sediments is rapidity of accumulation.

> The general geological record seems to indicate that it is only when a region with a red regolith is uplifted and relatively rapidly dissected that red sediments result. The fact that the red sandstones and shales are dominantly non-marine supports this view.

Barrell (1916) emphasized the role of seasonal rainfall as a significant factor in the origin of the Old Red sandstone, and Twenhofel (1939, pp. 317–18) has concluded that the sites of accumulation of red alluvium were drier than the source areas where the red soils were formed.

> The most favorable condition for deposition and preservation of color of red sediments on land areas lies between the extremes of some degree of moderate rainfall and semiaridity under relatively high temperature conditions. Deposition need not have been extremely rapid, but rapid deposition would have been a favorable factor.

Krynine (1937, 1938, 1941, 1947) postulates a warm, moist climate both at the source area and in the basin of deposition, but recognizing the importance of a seasonal distribution of rain, he has carefully emphasized the significance of a savanna-like, tropical to subtropical climate in the production of red sediments. The red Triassic formation of Nevada and Utah is considered to be the

> product of concomitant violent erosion and intense chemical decay. Like the Triassic of Connecticut and the Lower Siwalik of India, it was apparently formed in a sharply dissected region under a hot and very humid climate with seasonal rainfall (1938, p. 96).

Reed (1929) has postulated a similar environment during the accumulation of the red Sespe formation of southern California. After detailed study of the Lower Siwalik series, a thick deposit of red mudstone cut by numerous lenses of channel sandstone (schist arenite), Krynine (1937) inferred that the sediments accumulated on a well drained, slightly sloping piedmont plain in a tropical or subtropical savanna environment where the proportion of forest to prairie fluctuated widely according to the precipitation. In a source area of moderate relief deep chemical weathering produced the fine-grained red clastics which were carried to the basin mainly during dry seasons by sluggish rivers, and deposited on broad flood plains. Subaerial, post-depositional decay of the alluvium was retarded by rapid alluviation. During seasons of heavy rainfall streams were powerful enough to cut through deeply decayed red soil to fresh bedrock, and so carried medium-grained clastics to the basin. The proportion of fresh and weathered material that was eroded depended on relief and the distribution of rainfall. Adequate separation of coarse sand and fine red clay probably was controlled by seasonal rains conducive to floods and high and low water periods with sharply differing stream velocities. Similarly, Krynine (1947) has concluded that the predominantly red Newark series in the Connecticut Valley was deposited in a savanna environment of alter-

nating open parks and dense forests, with a humid tropical climate characterized by a uniformly high temperature (possibly 80°F.) and a heavy rainfall exceeding 50 inches annually but with a marked dry season lasting at least 3 months.

Origin of red layers in variegated deposits.—Inferences from redbed studies, and available evidence as to the paleogeography of the Rocky Mountain region during early Cenozoic time point to the conclusion that the red layers in the varicolored formations were derived from red upland soils developed in a warm, humid region.

Deposition and preservation of the red mud probably took place in a seasonally humid, warm-temperate to subtropical environment, much like that of southeastern United States or of the northern part of the Great Valley of California.

The predominance of illite in most of the variegated layers analyzed (Table III) can not be interpreted as supporting evidence, and may be a serious contradiction of the conclusion, especially if future work should reveal that kaolinite developed in red upland soils is preserved in derived alluvium. It should be noted however, that kaolinite has been identified in some of the samples, suggesting that kaolinite clay may have been present in the source soils.

Suggested Origin of Color Variation of Red-Banded Deposits

Role of plant débris

A satisfactory hypothesis of the origin of redbeds and of red-banded deposits must account for the variation of color within the formations. If it is postulated that red mudstone was derived from red soil, one might assume that the drab pigment was derived from drab soil in the source area. But drab soils are not characteristic of upland areas in a warm, humid environment, and there is no evidence of alternating climatic changes sufficient to produce red, then drab, soils.

Tomlinson (1916, p. 173) inferred that the drab layers in redbeds resulted from color changes at the place of deposition, not from a change of source material, because red and drab layers are indistinguishable in most characteristics other than color. According to this interpretation the hematite was transported and deposited as a fine-grained sediment, and by normal sorting by running water the red clay complex settled out mainly with mud; very little settled out with coarse sand. If sufficient organic matter was incorporated during transportation and deposition, the ferric iron was reduced, producing a drab color. The ratio of iron oxides to organic matter thus is the dominant factor determining the color of the mudstone.

Similarly, it is postulated that the sediments of both red and drab layers in varicolored formations were derived from red upland soils and deposited on flood plains in a lowland region. Red mud accumulated when little organic matter was incorporated at the place of deposition, whereas drab deposits resulted from reduction of the ferric oxide in the presence of decomposing plant débris. The smaller quantity of total iron in all drab samples (Table II) is consistent with

Keller's demonstration (1929) that during the reduction of hematite in sediments some ferrous iron is removed in solution. The interpretation of the mottled zones between red and drab layers as due to partial alteration of red material also accords with this hypothesis.

Moreover, such an interpretation of the origin of red-banded formations seems to be corroborated by the association of lignitic layers with drab strata. The faunal record offers further suggestive evidence, for although ungulate and carnivore remains are scattered throughout the variegated deposits, forest faunas of small arboreal animals have been recovered chiefly from drab layers.

DEPOSITION DURING ALTERNATING MOIST AND DRY PERIODS

Russell (1889) and Tomlinson (1916) concluded that alternate dry and moist periods at the place of deposition account for the red and drab colors of strata in redbeds. During dry periods the primary red color of the alluvium was preserved; during moist intervals the color was changed to drab by incorporated plant material.

An alternation of dry and moist periods may also have been the controlling factor in the origin of the color variation in red-banded deposits. Accordingly, the red sediments would have accumulated during seasonally humid intervals in a savanna-like environment. During periods of constantly humid climate red sediments carried into heavily forested lowlands would have been altered to drab deposits by the incorporated plant débris.

The range of thickness of the red and drab layers, together with available data on the rate of accumulation of sandstone and shale, indicates that the recurrent moist and dry periods would have persisted many, perhaps hundreds of years. Because flood-plain deposits are lenticular, each period of climatic variation is now reflected only locally in the mudstone lenses, even though the change had affected an entire basin area. The irregularities in thickness of the layers may be due to changes in the rates of accumulation at any one place, to the distance from the source, and to periods of different duration.

That cyclic climatic changes are not an uncommon geological phenomenon is suggested by pre-Pleistocene rhythmic sedimentation (Bradley, 1938) such as that found in the Green River formation and in the Oligocene White River group (Wanless, 1923, pp. 236–49).

Presumably periodic alternation of climate would have affected sedimentation throughout an extensive region. The fact that all the variegated formations are not the same age suggests, on the contrary, that factors local to each basin controlled the accumulation of alternating red and drab sediments.

DEPOSITION IN OPEN COUNTRY AND IN FORESTS

As an alternative hypothesis it is suggested that red and drab lenses may have been formed simultaneously in a savanna-like environment, the red beds resulting from deposition in the parks, while drab sediments accumulated in

forest swamps of abandoned meanders, in swampy basins between natural levee slopes, and in other heavily wooded areas. As the aggrading streams meandered across the basin floors, the location and environment of deposition were constantly shifting. Such a savanna environment could have prevailed in one basin while in other, perhaps nearer sea level and with lower peripheral uplands, forests were widespread and only drab deposits accumulated.

This interpretation is competent to explain the stratigraphic relationships of the variegated formations and to account for the color-banding throughout the basins if the following assumptions are made: first, that in a savanna the vegetation of the forests and parks is different enough to effect drab and red flood-plain deposits, and second, that beyond the forest-fringed banks of the permanent streams of moist savannas, part of the flood plain is open country.

Conclusion

In his classic study of the relation between climate and terrestrial deposits, Barrell (1908) demonstrated that the sedimentary effects of climatic variation are of great geologic importance. Through geologic time the slowly but perpetually fluxing climate has exerted a primary control, subordinate only to topography, upon the rate and type of erosion and the kinds of material supplied to the streams on the one hand, and on the other, upon the chemical, organic and structural characteristics of the sediments.

The present review emphasizes the necessity of understanding the effects of modern and ancient climates in paleogeographic studies. Future work on the problem of the origin of red-banded early Cenozoic formations must include observations of processes of sedimentation effective in modern warm, humid environments like that which prevailed in the Rocky Mountain region in early Cenozoic time. There is also need of much more detailed study of the variegated mudstone layers and particularly of the mottled zones between beds of different color. Further analyses of the clay minerals in the red-banded deposits and in recent soils and derived alluvium should yield important evidence about the source of the sediments and the environment of deposition. Detailed description of the graywacke and arkosic sandstone layers will amplify present understanding of the relation of sandstone types and depositional environments, for important evidence as to the geographic and tectonic environment is supplied by other data.

Two consequences follow from the hypothesis that the variegated early Cenozoic deposits were derived from red upland soil. First, other variegated formations such as the Jurassic Morrison formation, may have had a similar origin. And second, thick drab Paleocene sediments may also have been derived from red upland regolith, the alluvium accumulating in a constantly humid, heavily forested lowland where drab colors were produced. In such an environment plant débris would frequently have accumulated rapidly enough in local swamps to form beds of lignite such as are commonly present. Although these consequences

appear to be consistent with the available evidence, they must be tested by detailed study of the formations involved.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2127-2139, 5 FIGS.

RELATIVE ROLE OF SOME GEOLOGICAL TOOLS IN OIL EXPLORATION[1]

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ABSTRACT

Geophysical methods of oil exploration are seen as special methods of geological mapping, that is, as geological techniques or tools. Geophysics measures physical properties of the earth, which become geological data after suitable translation. The translator must have a full training in geology and should have practiced geology for a sufficient length of time. Conventional geological tools, such as hammer and compass, are still modern. The evolution of a geological section by integration of geological, seismo-geological, and electro-geological data is demonstrated by means of a generalized case.

Claims of success of geophysical methods independent of geology are discussed. It is considered that these should be related to the area of an entire country rather than to the area of oil provinces within a country.

A plea is made for integrated symposia on regional geophysical geology and for more publication of data on geophysical failures in order to find out possible underlying causes and thus criteria for selecting the most logical mapping techniques in each case.

INTRODUCTION

With the campaign for new oil fields in progress all over the world, eyes are focussed on the tools of exploration. There are indications that new tools will be used and that some conventional ones have become obsolete. Oil exploration, in a sense, is like war. In war, classical concepts of strategy remain immutable while tactics are adapted constantly to new weapons. In oil exploration the philosophy —the strategy—of oil finding likewise remains fairly stable whereas methods of exploration—the tactics—of oil-finding change. However, few tools of exploration lose their value entirely if used appositely for the purpose to which they are best adapted.

From time to time, opinions are voiced that geology, especially surface geology, is obsolete as a method for oil finding; it is even claimed that such a modern method as seismic exploration has reached the stage of diminishing returns and some conclude that one must resort to random drilling. Nothing could be further from the truth. Firstly, it must be realized that all tools and methods of exploration are relative in value and effect and secondly, that they can accomplish only an incomplete, imperfect, or even unnecessary piece of work, when used alone, in the wrong place, or too late. Each of the exploration tools has its own resolving power; each one can reveal something which the other one can not; but none can give the full picture alone. Every tool of oil exploration is used to gather basic physical or chemical information which, after geological interpretation, may lead to the discovery of oil in the earth, for the distribution of oil underground is governed by geological laws; hence, all tools of oil exploration are geological tools, and it is the purpose of this article to illustrate this fact and the need for geological interpretation.

[1] Manuscript received, May 17, 1948.

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New tools of exploration may still be invented and brought into action; these will affect the methods (the tactics) of exploration, but not its philosophy (the strategy). Of the tools now in vogue, only a few are here considered—the classical hammer and compass, the seismo-geological, and the electro-geological tools.

Study of geology has shown that oil occurs only preferentially, in certain areas of the earth; therefore, the first phase of exploration for oil is the elimination of impossible areas. Nobody would look for oil in an area of pre-Cambrian schists, and if the seismograph fails to indicate structure in such an area it is neither to its credit nor to its discredit. In a possible area, there are normally two basic situations to be dealt with: either the geology is exposed and is one-layer geology, that is, free of unconformities, or it is unexposed. In the former case, the tools of classical geology (the hammer and compass) suffice to evaluate the oil possibilities; in the latter case, tools of deeper penetration and more three-dimensional resolving power (the seismograph *et cetera*) must be brought into play.

CLASSICAL GEOLOGICAL TOOLS

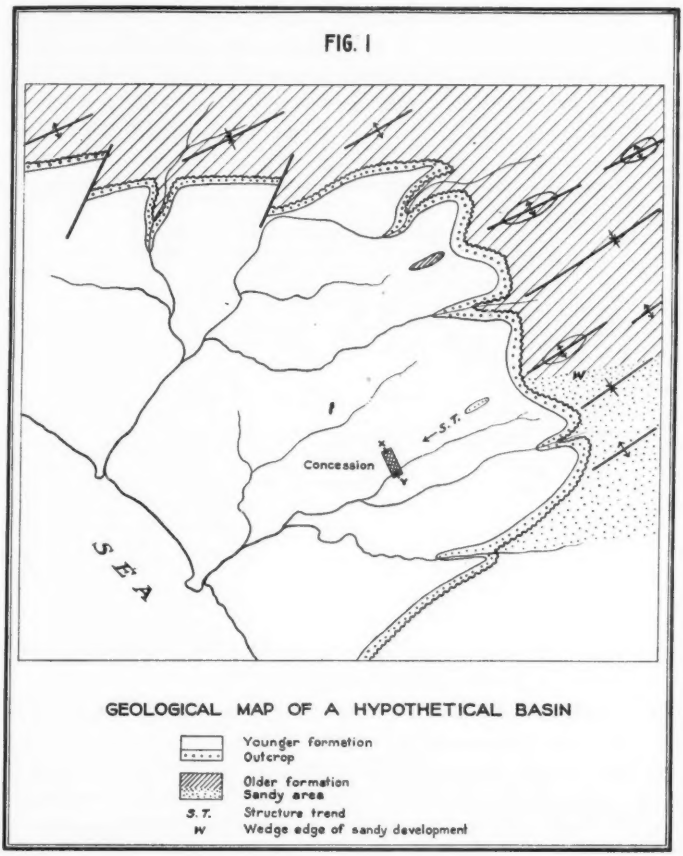
The classical geological tools are the hammer and the compass-clinometer. The hammer is used to test lithologic characteristics and the compass and clinometer serve to determine the attitude of geological bodies, that is, dip and strike of beds.

The test case selected is the same as will be used to illustrate the resolving power of the seismo-geological and the electro-geological tools; it is a block of land in a basin away from its border and covered by young formations. How can geology, under these circumstances, be any guide to the underground and more specifically to the oil prospects of that underground? The answer is by methods of regional correlation and extrapolation. The resulting guess—the tentative geological section—will be inaccurate and qualitative only and its principal value will consist in helping to select and to guide the more penetrating and therefore also much more costly tools such as the seismo-geological and the electro-geological tools.

Before considering the tentative section in detail, consider Figure 1, a sketch map showing the situation of the exploration block referred to, relative to the border region of the hypothetical basin. It is assumed that the borderland of the basin has been mapped previously by one of the conventional surface mapping methods, that structure trends are known, and that the stratigraphy has been established. By extrapolation of regional structural and stratigraphical trends from the rim basinward, the exploration block is geologically evaluated on a regional scale and the tentative section (Fig. 2) is prepared. It shows the approximate type of geology expected to underlie the exploration block. Three predictions of the forecast deserve to be pointed out: firstly, the presence of a thick, almost undisturbed younger formation (the younger geological layer) separated from the lower and older layers by an unconformity. The young formation has

been mapped and the unconformity is extrapolated from the conditions found in the rim area of the basin.

Secondly, based on the structural trends at ST (Fig. 1), the geologist suspects the presence of mild structural relief in the form of an anticline. Thirdly, he antici-



pates thickening of formations, especially of lower sands, and thus hopes for possible presence of stratigraphic traps based on conditions indicated at W in the rim area of Figure 1.

SEISMO-GEOLOGICAL TOOL

The problem to be considered here is to discover exactly what the seismograph —the seismo-geological tool—reveals, where in the exploration campaign is its

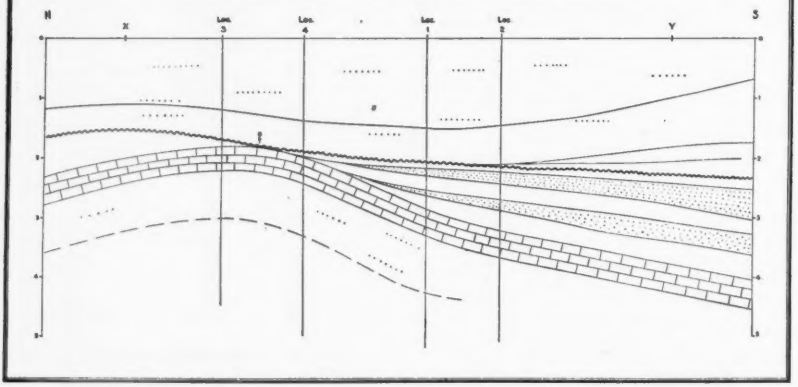
place, how is the intelligence which it produces used, and by whom is it interpreted.

Consider the hypothetical case. On geological, not geophysical, grounds the area of exploration is chosen. However, the best place for a test is still to be found. Conventional geological reconnaissance finds the terrane obscure, covered by thick alluvium and further by a layer of young uncharacteristic beds. In other words, one is almost in the center of a geological basin, which in itself is favorable for oil. The geologist, by extrapolation from the borders of the basin, forms certain ideas of the thickness and attitude of the geological formations which fill the basin. According to geological laws of oil occurrence, somewhere in the basin

FIG. 2

TENTATIVE GEOLOGICAL SECTION X-Y OF FIG. 1

BASED ON REGIONAL EXTRAPOLATION OF SURFACE GEOLOGY



there must be one or more oil fields. The seismograph party is called into action and runs a number of lines across what the geologist calls the regional strike and it returns with a set of data which can be pieced together into a section (Fig. 3).

This picture is, of course, entirely hypothetical and neither composed to show the exclusive penetrating (resolving) powers of the tool nor to show its shortcomings. What one sees is a series of lines and dashes spread over a depth range of 5,000 feet. In the first 1,000 feet there are only a few dashes while the left center of the picture appears to be devoid of them. Apparently, the tool has not registered anything; it can not see; it is blind in this spot. Some of the dashes run reasonably parallel with one another, others run in odd directions and are labelled "anomalous." On the whole, there seems to be a system in the arrangement of these dashes. The seismologist reports that some dashes are related to others and indicates their relationship by connecting lines; he also reports that some of the dashes are reliable while others are questionable.

What is then represented by these dashes? Geophysics measures certain physical properties of the earth's crust. In the case selected, shock waves are created by means of explosions. These waves travel through the earth's crust and, on meeting with obstacles, are reflected back to surface, where they are picked up by the seismograph. These obstacles in the path of waves are boundary layers separating one medium from another of different physical properties. Wave reflections can be related to the reflecting boundary layer and on mathematical analysis reveal the attitude in space, in the earth's crust, of the boundary layers, or boundary planes. The geometrical projection of such planes on a vertical section plane is a line in a reduced scale—a dash. Thus, each dash seen in the section (Fig. 3) represents the projection of an individual reflecting plane. The seismol-

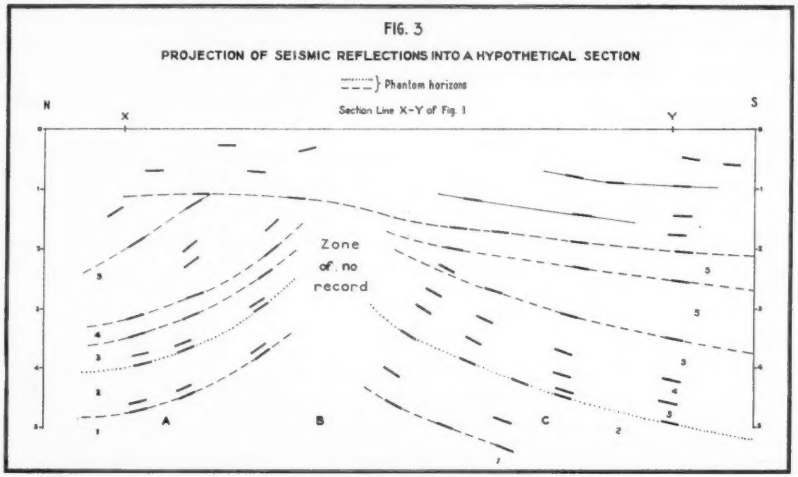


FIG. 3

PROJECTION OF SEISMIC REFLECTIONS INTO A HYPOTHETICAL SECTION

ogist is able to make further statements about these planes. Shock waves travel faster in denser than in lighter media and by taking account of the speed of the waves the seismologist can classify the various reflections registered by the seismograph and he indicates relations between reflections by connecting them with lines.

Summarizing, one can now say that the product of geophysical, in this case seismic, exploration is a geophysical map and a section through the earth's crust, revealing the arrangement in space of a discrete and incomplete system of reflecting planes, graphically expressed as dashes. The compilation of this section completes, in general, the task of the seismologist. He has supplied the information his tool can give, and this information is in the form of a coded message. The message of the dashes—of the reflecting planes—must now be translated into terms which permit of evaluation and formulation of a plan of further exploration.

What method of decoding will bring success, and who is the decoder? Here, re-appears geological science and the geologist, to whom the dashes mean dips of the boundary layers between geological formations or beds or rocks. Different velocities or refraction may indicate beds of sandstone, limestone, or shale, or beds of various degrees of compaction. The geologist segregates the section into geological, in this case structural, components; in other words, he sees structure. The area "A" will become a north flank with north-dipping beds; the area "C" will be the counterpart, a south-dipping flank with south-dipping beds; the area "B," by extrapolation, is to him either a zone of faulting or more probably the crestal zone of an anticline—a structure. On the south flank he will note certain convergences and suspect thinning of beds; certain anomalous dips in area "C" in the 3,000-foot level are perhaps due to cross-bedding, whereas other dips in area "A" in the 1,000-foot level may indicate unconformable beds. In other words, the seismograph message is being translated into geological terms of structure and lithology and, since the area reconnoitered is in a possible oil basin, the geologist will now recommend reconnaissance in force with heavy tools, that is, with the drill.

The term "anomalous" used in this paragraph is relative and dips considered to be anomalous are only so relative to a plurality of other dips sharply differing from the so-called anomalous ones, but alike among themselves. The use of the term "seismo-geological" in the heading now becomes understandable; it denotes the fact that seismic data are used for a geological purpose and in a geological sense.

ELECTRO-GEOLOGICAL TOOL

Among the electrical tools, the one outstanding for oil exploration is the electrical log—the record of the electrical character of the formations exposed in a bore-hole. A complete set of electrical records of a bore-hole consists of recording the electrical properties of the media penetrated, a record of the attitude of beds, and of the deviation of the bore-hole from the vertical. These properties can be measured so as to permit interpretation in various terms, all useful for oil finding.

First, four holes are to be drilled. Two are located on the south flank, simply because that flank seems gentler, longer, and less disturbed. The fourth location is kept in reserve; it is later used to check the center, the crest of the structure. For the sake of simplicity, the electrical measurements or the logs are plotted to scale in the form of parameters against depth, on a vertical line representing the axis of the bore-hole. The graphical logs are then assembled and transposed to the section line x-y, as shown in Figure 4, which is the same line of section as used in Figure 3 to illustrate the results of the seismic exploration.

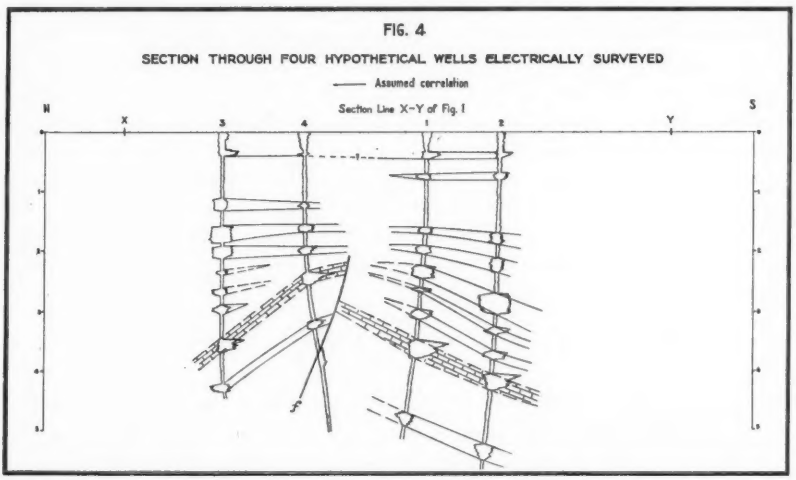
On this figure the electrical logs appear as more or less vertical lines adorned like maypoles. The ornaments are the graphical representation of maxima of self-potential (SP) and resistivity (R) effects measured by millivolts and ohm meters, respectively. These parameters are the expressions of the electrical character of the earth's crust penetrated. Briefly, the SP effect is considered to be the result

of a number of geo-electrical features, among them one somehow related to the porosity of the formation logged; the resistivity effect is due to resistance of rock material, and fluid therein, to passage of electrical currents. On the simplest philosophical grounds, like and like belong together; hence, a few lines have been drawn on the section to denote possible or probable relations. These lines connect identical, similar, or at least relatable electrical behavior. By drawing these lines, the first step in the translation of the electrical message into a picture which can be used for purposes of oil finding is accomplished.

To become intelligible for oil finding, this translation must become an inter-

FIG. 4

SECTION THROUGH FOUR HYPOTHETICAL WELLS ELECTRICALLY SURVEYED



pretation; physical terms must be translated into geological terms and geological terms must be interpreted according to geological laws. By previous experimentation, one has ascertained the general relationship between different types of rocks and their electrical character as expressed in SP and R values or effects. Since these relations are known to a sufficient degree, the translation of the electrical message—the electric log—can proceed speedily. On the log all zones with minimum SP and R showing as two parallel lines are determined as shales, or clay, and intervals with high SP effects are logged as sands; those with low SP effects but high resistivity are logged as essentially cemented, probably calcareous formations. This step in the translation supplies an inventory of the lithology of the geological formations and beds penetrated by the drill and the depth at which they occur. The third step in the interpretation is concerned with the evaluation of indications of the fluids present in the porous zones. The shale zones are, of course, eliminated; all the zones with R and SP effects greater than that of, or different from, shales contain some fluid. Those showing low resistivity are

logged as salt-water zones and those which high resistivity are considered to contain oil or gas or, in certain cases, fresh water.

Summarizing, one may say that the electrical logging has produced a record in physical terms, that is, in terms of millivolts and ohm meters, of the part of the earth's crust penetrated by the bore-holes which, upon translation into geological terms, yielded three messages: that of relation (correlation), that of lithology, and that of fluid content. Again, without decoding and translating into geological terms, the messages would have remained theoretical and of no immediate value, excepting for the academic geophysicist studying general laws of distribution of geo-electricity. To make the message intelligible for oil finding, a translation into geological terms was necessary and only inasmuch as this translation is correct is the message of any immediate practical value.

The decoded message permits formulation of a testing program, and on the assumption that the ensuing tests were successful, the exploration campaign is completed. The electrical log, a device created by physical science based on physical laws, is a geological tool essential to confirm certain information supplied by the dip needle or by the seismo-geological tool, furthering exploration by permitting an appraisal of the fluid content of prospective formations. Thus, it is a most important, decisive tool leading to abandonment or development of prospects. Yet its use in the last instance is geological, guided by principles of geology; hence, the term "electro-geological" tool.

INTEGRATION OF MAPPING TECHNIQUES AND COMPOSITE SECTION

The line of section of Figure 2 coincides exactly with the section lines of Figures 3 and 4 and also with that of the composite, the revised geological section, Figure 5. Comparison of the tentative section (Fig. 2) with Figure 5 reveals that the first section is only a crude simplification of the actual conditions; it is approximative only; yet this tentative section was sufficiently interesting to have led to intensive seismo-geological exploration and finally to drilling and electro-geological exploration. The composite geological section of Figure 5 is the result of piecing together geological evidence from all sources.

Clearly, most of the seismic reflections originated in true formation boundary layers. However, some of them came from odd levels within formations and are possibly reflections from compaction planes. It becomes evident now that the electro-geological tool has furnished the bulk of the lithological and fluid picture while the seismo-geological tool supplied the structural skeleton. The general type of geology, however, remains as forecast by the geologist.

CHOICE OF EXPLORATION TOOLS

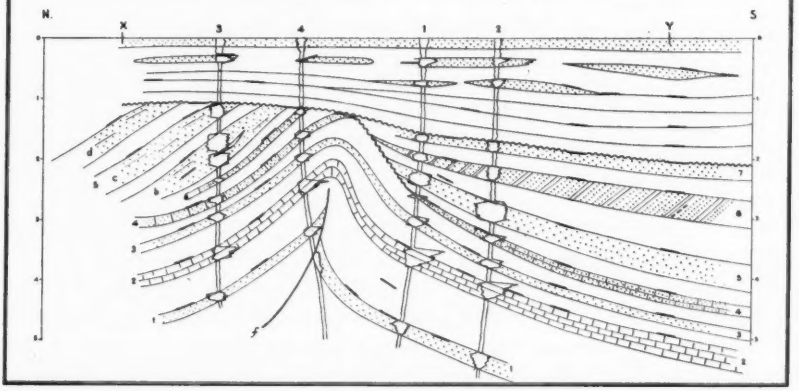
In measuring the attitude of beds, the geologist used geometry and geophysics; inclination and azimuth are both measured in degrees and are purely geodetic quantities which also require translation into geological terms of dip and strike before they become of geological significance. This translation is, how-

ever, so self-evident that the geologist himself is apt to forget that his oldest tool, the compass clinometer is, in fact, also of geophysical origin, and although rudimentary and simple, it is related qualitatively to the more refined tool, the seismograph—the dipmeter of the 20th century.

Of the tools available to the geologist for solving problems of oil exploration, only three have been considered: the classical hammer and compass, the seismo-geological seismograph, and the electro-geological electric-logging device. The nature of the properties which these tools can reveal has been reviewed and it was demonstrated that in every instance these properties, physical in nature,

FIG. 5

HYPOTHETICAL COMPOSITE GEOLOGICAL SECTION ALONG LINE X-Y OF FIG. 1
BASED ON SEISMIC DATA, ELECTRIC LOG OF WELLS 1-4 & REGIONAL GEOLOGY.



require translation into geological language before a prospect can be assessed; put in another way, it is evident that an oil prospect is commonly evaluated in geological terms and not in either purely seismic or electrical terms.

In reconnoitering the oil possibilities of a country, the choice of the correct set of tools and the sequence in which they will be employed is rather important. It would be foolhardy to go into an unknown area in search for oil and leave the classical tools behind and start action at once with geophysical, for example, seismo-geological, tools. The danger, apart from financial effects, is that geological thinking might also be left behind and such a policy would lead, at best, to sporadic exploitation.

Obviously, the first tool to be used is the hammer and compass. The first crop of dips is collected by the geologist who also investigates the stratigraphy of the area; the first reconnaissance survey is made by surface geological methods. This may be supplemented by air-mapping. The choice of tools for the second phase of exploration, the intensive phase, depends on the findings of the first one. In

many cases it will be necessary to resort to tools of deeper penetrating power; the seismologist will be able to secure dips where the conventional geologist can not, but while the geologist hunts geological horizons, the seismologist pursues boundary effects.

It is true, in general, that the geologist has not mastered the seismo-geological tool, and too often he has restricted himself to the role of a critic sitting on the fence. This is understandable, because mastering of the seismograph is complicated enough to be a full-time occupation.

The third phase of reconnaissance (the verification of prospects) must be undertaken by the drill supported by the electrical-logging tool. The drill, in a strict sense, can also be considered as a geological tool and will have to be used as such more and more in order to secure the necessary geological (mainly stratigraphical) information of the third dimension, when other tools are insufficient to render a decision.

All tools of exploration are specific and it is not the object of this article to judge in absolute terms the merit of each tool as an oil finder but rather to show what kind of message they reveal and where and at what stage they are needed in the process of exploration. There are known cases of false uses of tools or of using a good tool at the wrong time. One instance is that of a search for fields in which geophysical methods were used. Later, it became known that of the 27 fields, 24 had surface expressions and could have been found by surface mapping.[3]

Many tools are indispensable to modern exploration. If a tool is as simple as a compass, its use does not require a specialist; if the tool is complex and costly, it is obviously good economy to let it be used under the care of a specialist, who, however, need not be the evaluator or interpreter of the data measured. The nature of the data measured by each tool is physical, the interpretation is geological, and as long as no new scientific philosophy of oil finding is developed, oil exploration will be dominated by geological concepts and geological thinking, and be guided by geological knowledge of crustal formation and associated forms of oil accumulation.

This problem of the nature of the relations between the geologist and the geophysicist has been summed up admirably by Alexanian[4] in his text on practical geophysics from which a passage on page 3 of the introduction may be quoted in translation.

> Every physical property of the crust of the earth which can be measured by a method borrowed from modern physics is the subject of a special chapter of geophysical prospecting. In other words, here we have physics applied to geology and the declared aim of geophysical prospecting is to contribute to geological exploration by means of a physical study of the region. In this manner the geophysicist presents the results of physical measurements to the geologist who then interprets them in geologic terms in an effort to confirm or reject his own considerations of the same region.

[3] R. Dana Russell, "Future of Field Geology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 2 (1941), p. 324.

[4] C. L. Alexanian, *Traite Pratique de Prospection Geophysique.* Introduction, p. 3. Paris (1932).

RELATIVE SUCCESS OF VARIOUS OIL-EXPLORATION METHODS

Statistics appear annually in various journals purporting to show the relative success of different methods or tools for oil finding. Figures are commonly cut to fractions and are quoted with apparent pride. The following current figures are from an article by V. G. Gabriel.[5]

During the period 1938–43 inclusive, the probability of obtaining a producing well from exploration was—

(1) 1:20.6 for wells based on miscellaneous non-technical reasons;
(2) 1:6.1 for wells based on Geology;
(3) 1:5 for wells based on Geophysics;
(4) 1:4.4 for wells based on a combination of Geophysics and Geology.

Obviously, nobody will use expensive geophysical tools outside what is not already recognized to be an oil province, and likewise no one will resort to random drilling outside already suspected petroliferous ground. The person who recognizes an oil province is the geologist, who bases his appraisal on regional geological correlation. Therefore, the success of geophysics as measured by the relation cited refers to success within an oil province, and similar reasoning applies to the success cited for random drilling.

In a very liberal view, approximately 20 per cent of the area of a large country may be classified as probably oil-bearing, and if the term geophysics is understood to mean pure geophysics not tainted by geology and if random drilling is understood to mean non-selective drilling on non-technical grounds and if success is related to the total area of the country (the country must be large enough for statistical laws to be applicable), the respective corrected claims are as follows.

Successful exploration wells based on pure geophysics: approximately 1:20
Successful exploration wells based on random drilling: approximately 1:100

These ratios differ somewhat from those previously claimed, but they give a truer picture of the situation and probably they are still too favorable. In fact, no oil is found without some sort of geology, and when evaluating oil-finding methods it is more nearly correct to speak of geophysical geology than of geophysics alone and of selective random drilling than of non-technical random drilling, for most of the wells located on non-technical grounds are located within oil country, and in fact on a combination of geomorphological and structure-trend thinking, apart from those located for legal reasons. Many so-called wildcatters have acquired unconsciously a shrewd experience in evaluating geomorphological features in a manner similar to the water-diviners, who believe that they find water by the divining rod when in reality they rely on their geomorphological experience.

Thus, a more nearly correct statement of statistical success appears to be the following.

[5] V. G. Gabriel, "Mathematical Chance of Finding Oil," *Oil Weekly* (May 21, 1945).

Method of Exploration	*Ratio of Success*
Selective random drilling	1:20
Conventional geology	1:6
Geophysical geology	1:5
Conventional plus geophysical geology	1:4.5

Of a similar nature are the claims of geochemists; Horvitz[6] claims an "elite" status for his geochemical method, although in combination with a seismic check. It is quite conceivable that his method may excel under certain conditions and in certain specific areas previously known as petroliferous by regional geological correlation, but in the last instance it is geology which supplied the philosophical background leading to geochemical success.

CONCLUSIONS

If the points made are convincing, then improvements in geological theory and interpretation of data obtained by means of any geological tool should increase the chances of locating oil underground and therefore the next step should be to re-examine systematically and, if possible, to sharpen geological methods of interpretation and evaluation. In addition, it appears to be advantageous to assemble in one symposium a systematic collection of geophysical patterns in form of maps and sections of areas of which the geological interpretation has been verified by the drill. Such a collection could serve as a guide to quicker and better interpretation of new geophysical data. It is gratifying to read that the Society of Exploration Geophysicists intends to publish such a collection of test cases.[7]

A further necessity is to improve the interpretation of electrical logs. Many projects of log interpretation are under way and great progress has been made in the last years; reference is made to the paper by Guyod[8] and to the collection of electrical logs of Colorado by the Colorado School of Mines.

Relatively little is known about the electrical characteristics of steeply dipping sands, cross-bedded or slumped sands. Comparatively little has been published on the seismic expression of irregular sedimentation (fore-set bedding, large-scale slumps, unconformities, cyclical sedimentation, *et cetera*) or the effect of fluid in the reservoirs on the seismic record. The term anomaly is rather loose and should be avoided where possible; it should be used only if the complexity to be described can not be recognized as lithological or structural.

It would be interesting for the geologist to see regional seismic dip sections through entire geological basins and across series of anticlines. Very little seems to be published in journals read by the average geologist about geophysical fail-

[6] L. Horwitz, "Recent Developments in Geochemical Prospecting for Petroleum," *Geophysics*, Vol. 4 (November, 1945), p. 407.

[7] H. C. Cortes, "Publication of Geophysical Case Histories," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 7 (1946), p. 1095.

[8] H. Guyod, "Electrical Well Logging," *Oil Weekly* (August 7–December, 1944).

ures, for example, about the zones of no reflections and what causes them. A comparative geological study of failures of the seismograph or other geophysical instruments to produce records should yield useful results.

This review would not be complete without a plea in this case for joint papers of a more general nature by teams of geophysicists and geologists. A correct reply to such questions as "What is the regional geology of the prospective area?," "What are the most economical tools to be used?," "In what sequence should the tools be used?," will not only improve the chances of finding oil, but will also make exploration less expensive.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2140-2143

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

REVIEW OF PETROLEUM GEOLOGY IN 1947, BY F. M. VAN TUYL, W. S. LEVINGS, L. W. LEROY, ET AL.

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

"Review of Petroleum Geology in 1947," by F. M. Van Tuyl, W. S. Levings, and L. W. LeRoy, with the co-operation of faculty members of the Colorado School of Mines and others. *Colorado School of Mines Quarterly*, Vol. 43, No. 3 (July, 1948). 334 pp., including table of contents, abstract, introduction, bibliography, list of contributors, and two illustrations. Sponsored by A.A.P.G. research committee. Published by Department of Publications, Colorado School of Mines, Golden, Colorado. Price, $3.00.

This annual review of accomplishments in petroleum geology and allied sciences and techniques has made its sixth prompt appearance, and for the fifth time has increased its size over the preceding volume. The new volume contains 334 pages, subdivided under the customary section heads: Important Developments of the Year (news of men and societies) 31 pp.; Advances in Petroleum Geology and Allied Subjects, 87 pp.; Aerial Photographs, 4 pp.; World Exploration and Development, 51 pp.; Production and Reserves, 14 pp.; Trends in Petroleum Geology, 10 pp.; Future of the Oil Industry, 2 pp.

The textual information is followed by a bibliography of 127 pages, containing almost 3,500 entries, which is classified in the same manner as the text. This bibliography is of necessity the most valuable part of the review for it serves as a prompt, convenient, and reasonably exhaustive index of the available literature on important activities in oil technology and oil-finding in 1947.

The section on World Exploration and Development has been trimmed somewhat nearer the highlights of the year in the oil-producing areas, which is more in line with the purpose of this summary and less liable to conflict with the detailed annual reviews in the *Bulletin* of the A.A.P.G. and other recognized scientific and statistical publications.

Again the petroleum technologists and others interested in the scientific advances of the petroleum industry should feel grateful that Dr. Van Tuyl and his associates have been able to publish this compact and comprehensive summary for their information.

RECENT PUBLICATIONS

ARCTIC REGION

*"Ancient Arctica," by A. J. Eardley. *Jour. Geol.* (Chicago, September, 1948), pp. 409–36; 8 figs.

ARGENTINA

*"Sobre la presencia de carbonifero inferior en la Sierra de los Llanos" (Lower Carboniferous in Los Llanos Sierra), by Osvaldo Bracaccini. *Y.P.F. Bol. Inform. Petrol.*, Vol. 25, No. 281 (Buenos Aires, January, 1948), pp. 63–94; 16 figs., correlation chart. Spanish.

[1] Amerada Petroleum Corporation. Review received, September 29, 1948.

ATLANTIC COAST

"Studies of the Subsurface Geology and Paleontology of the Atlantic Coastal Plain," by Horace G. Richards. *Proc. Acad. Nat. Sci. Philadelphia*, Vol. 100 (August, 1948), pp. 39–76. Price, $1.25.

BORNEO

* "On the Contemporaneous Occurrence of Lepidocyclina and Discocyclina in Northern Borneo," by M. G. Rutten. *Geologie en Mijnbouw*, Vol. 10, New Ser., No. 8 (August, 1948), pp. 170–72; 1 pl. Published by G. A. Tiesing, Vogelkersstraat 48, 's-Gravenhage. In English.

ECUADOR

* "Geologische Skizze von Ekuador" (Geological Sketch of Ecuador), by H. J. Tschopp. *Bull. Ver. Schweizer. Petrol.-Geol. u.-Ing.*, Vol. 15, No. 48 (Riehen-Basel, July 30, 1948), pp. 14–45; 3 figs., 1 table; bibliography of 91 titles. In German.

GENERAL

* *Bibliography and Index of Geology Exclusive of North America*, Vol. 12 (1947), Geological Society of America (1948), by Marie Siegrist and Eleanor Tatge. 359 pp.

"Geophysical Abstracts 133, April-June, 1948," by V. L. Skitsky and S. T. Vesselowsky. *U. S. Geol. Survey Bull. 959-B* (August, 1948), pp. 87–175. For sale by Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price, $0.25.

"Topographic Mapping [Appraisal and Supplementary Index for Topographic Instructions]." *U. S. Geol. Survey Bull. 788-E* (April, 1948). 4 pp. Free on application to Director, Geological Survey, Washington 25, D. C.

"Annotated Bibliography of Papers on Geochemical Prospecting for Ores," compiled by H. E. Hawkes. *U. S. Geol. Survey Cir. 28* (August, 1948). 6 leaves (processed). Free on application to Director, Geological Survey, Washington 25, D. C.

Statistics of Oil and Gas Development and Production (Covering 1947), assembled by Production Review Committee, E. G. Dahlgren, chairman, Petroleum Division, Amer. Int. Min. Met. Eng. (New York and Dallas, Texas, 1948). 514 pp. 6×9 inches. Cloth.

*"Aerial Photography and Exploration for Oil," by N. J. M. Taverne. *Journ. Inst. Petrol.*, Vol. 34, No. 296 (London, August, 1948), pp. 516–40; 11 figs., 8 pls.

GREENLAND

*"Stratigraphie der Jurabildungen Ostgrönlands" (Stratigraphy of Jurassic in East Greenland between Hochstetterbugten, 75° N., and Kaiser Franz Joseph Fiord, 73° N.), by Wolf Maync. Meddelelser om Grönland, Bd. 132, Nr. 2 (Copenhagen, 1947). 223 pp., 38 figs., 7 pls. Paper, 6.75×10.75 inches. Geological expedition to East Greenland in 1936–1938. Printed by C. A. Reitzels, Copenhagen, Denmark. In German. Price, Kr. 11.

GULF COAST

Texas Gulf Coast Oil, by Frank J. Gardner. A study of the Petroleum Industry in Twenty-Nine Counties of the Texas Gulf Coast. 317 pp. 8.5×11 inches. Spiral-bound. Contains (1) History of oil development, (2) Summary of the industry, (3) Tabulation of industrial plants, (4) List of fields by counties, (5) Compilation of individual field data, (6) Bibliography, and (7) Index. Published by Rinehart Oil News Company, Dallas, Texas (1948).

MONTANA

"Geology of the Lothair Area, Liberty County, Montana," by Charles E. Erdmann. *U. S. Geol. Survey Prelim. Map 87*, Oil and Gas Inves. Ser. (September, 1948). Map on

scale of 1 inch equals 4,000 feet. Sheet 30×40 inches. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.60.

NETHERLANDS

*"Militaire Geologie in Nederland (Military Geology in Netherlands)," by D. Lafeber. *Geologie en Mijnbouw*, Vol. 10, New Ser., No. 8 (August, 1948), pp. 157–70; 6 figs. Published by G. A. Tiesing, Vogelkersstraat 48, 's-Gravenhage. Abstract in Fnglish; text in Dutch.

NORTH DAKOTA

*"First Supplement 1948 Bibliography of the Geology and Natural Resources of North Dakota," by Chrissie F. Budge. *North Dakota Research Foundation Bull. 4* (Bismarck, 1948). 90 pp. Paper cover. 5.75×8.75 inches. 360 entries, annotated. Author and subject index.

OKLAHOMA

*"Secondary Recovery Possibilities of the Olympic Field, Hughes and Okfuskee Counties, Oklahoma," by I. W. Fox, R. L. Ginter, and G. P. Alden. *U. S. Geol. Survey Conservation Branch, Oil and Gas Leasing Division* (Tulsa, 1948). 106 processed pp., 34 pls. 8.5×11 inches. Copies upon application to Oil and Gas Supervisor, U. S. Geological Survey, Federal Building, Tulsa, Oklahoma.

PACIFIC REGION

*"Submarine Geology of Bikini Atoll," by Kenneth O. Emery. *Bull. Geol. Soc. America*, Vol. 59, No. 9 (New York, September, 1948), pp. 855–60; 5 pls.

*"Reefs of Bikini, Marshall Islands," by J. I. Tracey, Jr., H. S. Ladd, and J. E. Hoffmeister. *Ibid.*, pp. 861–78; 8 figs., 11 pls.

PENNSYLVANIA

**Early Days of Oil: A Pictorial History of the Beginnings of the Industry in Pennsylvania*, by Paul H. Giddens. 150 pp., 365 photographs with explanatory text. 8.5×11 inches. Cloth, pictorial paper jacket. Princeton University Press, Princeton, New Jersey. Price, $6.00.

PENNSYLVANIA AND NEW YORK

Guide Book to the Geology of the Northern Portion of the Appalachian Basin, compiled and edited by George C. Grow, Jr. Contains detailed itinerary of the field trip of the Pittsburgh regional meeting of the A.A.P.G., October 4–9, 1948, sponsored by the Pittsburgh Geological Society. 121 pp., with many maps, sections, charts. Contains "General Character of the Paleozoic Sediments from Western to Central Pennsylvania and to Western New York," by Frank M. Swartz. Pp. 91–115, and 3 stratigraphic charts. 8.5×11 inches. Leatherette cover and wire-o binding. Write to George C. Grow, Jr., 545 William Penn Way, Pittsburgh 19, Pennsylvania. Make checks payable to the Pittsburgh Geological Society. Price, $5.00.

PERU

*"Geology of the Arequipa Quadrangle of the Carta National del Peru," by William F. Jenks. *Inst. Geol. Peru Bol. 9* (Lima, 1948). 204 pp., 9 pls., 10 figs. Pp. 1–104, in Spanish; pp. 105–204 in English. 6.875×9.625 inches. Paper cover.

*"Die Petrolfelder von Pirin und Ganso Azul in Peru" (Oil Fields of Pirin and Ganso Azul), by Arnold Heim. *Bull. Ver. Schweizer. Petrol.-Geol. u. -Ing.*, Vol. 15, No. 48 (Riehen-Basel, July 30, 1948), pp. 10–13; 2 figs. In German.

TEXAS

*"Southwest Texas, Present Development and Future Possibilities," by William H. Spice, Jr. *Independent Monthly*, Vol. 19, No. 5 (September, 1948), pp. 31–36; geol. section and map showing location of fields.

UTAH

*"Geology of the Confusion Range, West-Central Utah," by C. S. Bacon, Jr. *Bull. Geol. Soc. America*, Vol. 59, No. 10 (New York, October, 1948), pp. 1027–52; 5 figs.

*"Key Permian Section, Confusion Range, Western Utah," by Norman D. Newell. *Ibid.*, pp. 1053–58; 2 figs.

* "Stratigraphic Sections of Jurassic and Cretaceous Rocks in the Jackson Hole Area, Northwestern Wyoming," by J. D. Love, D. C. Duncan, H. R. Bergquist, and R. K. Hose. *Geol. Survey of Wyoming Bull. 40* (Laramie, June, 1948). 48 pp., 2 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 18, No. 2 (August, 1948).

"Environmental Significance of Dwarfed Faunas. A Symposium," Foreword by the Editor.

"Dwarfed Protozoan Faunas," by Cecil G. Lalicker.

"Assemblages of Diminutive Brachiopods and Their Paleoecological Significance," by Preston E. Cloud, Jr.

"Environmental Significance of Dwarfed Cephalopods," by Bernhard Kummel.

"Significance of Crustaceans in Dwarfed Faunas," by Harold W. Scott.

"The Use of Peels in Carbonate Petrology," by Edward J. Buehler.

"Sediments from Pre-Cambrian Rocks of Southern Sangre de Cristo Mountains, New Mexico," by Raymond Sidwell and John L. Haliburton.

"Sediments of Oki Bank in the Japanese Sea," by Hiroshi Niino.

"Itabirite of Minas Geraes, Brazil," by Stanley A. Tyler.

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 22, No. 5 (September, 1948).

"Ostracoda from Middle Devonian Windom Beds in Western New York," by Frank M. Swartz and Steven S. Oriel.

"A New Lower Ordovician Trilobite," by H. B. Whittington.

"A Systematic Revision of *Daphoenus* and Some Allied Genera," by Jean Ringier Hough.

"*Astrodapsis* in Japan," by Syôzô Nisiyama.

"*Arbia* and *Dixieus*, Two New Genera of Echinoids," by C. Wythe Cooke.

"Lower Cretaceous Corals from Trinidad, B.W.I.," by John W. Wells.

"New Pennsylvanian Dibunophyllid Corals," by Russell M. Jeffords.

"A New Genus of Foraminifera from the Upper Cretaceous," by Cecil G. Lalicker.

"The Dentary of *Troödon*, a Genus of Theropod Dinosaurs," by Loris S. Russell.

"Chimaeroid Fossil Egg Capsules from Alberta," by P. S. Warren.

"A New Cretaceous Calcareous Alga from Kansas," by J. Harlan Johnson and B. F. Howell.

"Eocene Fresh-Water Mollusca from Wyoming," by Teng-Chien Yen.

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VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2144-2167, 16 FIGS.

ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Charles E. Erdmann, Andrew Alpha, Victor H. King

Charles Edward Davis, Arlington, Tex.
S. A. Lynch, Claude C. Albritton, Jr., M. E. Upson
Bart John Dillon, Austin, Tex.
J. A. Brooks, Jr., Decatur O'Brien, John W. Skinner
Edward George Duckworth, Denver, Colo.
Robert McMillan, George R. Wood, William Beer
Charles DeVries Edwards, Casper, Wyo.
A. F. Barrett, K. A. Gorton, Victor H. King
Charles Dey Foss, Los Angeles, Calif.
Joseph Jensen, Claude E. Leach, H. J. Steiny
Felix A. Galavis-S., Caracas, Venezuela, S. A.
K. F. Dallmus, James S. Cullison, G. Zuloaga
Robert Wiatt Garwick, Houston, Tex.
Wallace C. Thompson, Willard L. Day, James W. Kisling, Jr.
John M. Good, Houston, Tex.
Norman S. Hinchey, Julian K. Pawley, E. J. Smith, Jr.
Kempton Bishop Hall, Ojai, Calif.
Rollin Eckis, Irving T. Schwade, Clifton W. Johnson
Wilson Glover Harris, Jr., Mt. Vernon, Ill.
Jack L. Hough, Harold R. Wanless, H. W. Scott
Victor Edwin Hartwig, Houston, Tex.
George B. Somers, E. J. Barragy, F. W. Rolshausen
Jack A. James, Rolla, Mo.
Gerrett A. Muilenberg, Robert P. McNeal, Earl McCracken
Stephen Gray Johnston, Dumas, Tex.
Raymond Sidwell, Leroy T. Patton, W. I. Robinson
Joseph David Kennedy, Fort Worth, Tex.
Robert F. Imbt, Leo Hendricks, Ford Bradish
Robert Donald Knight, Houston, Tex.
Sherwood Buckstaff, V. W. Rogers, H. M. Goodman
Paul Hoyt Ledyard, Fort Worth, Tex.
F. H. Schouten, William J. Nolte, Sidon Harris
James Edwin Lewis, Satartia, Miss.
Keith M. Hussey, Carl A. Moore, F. A. Melton
Robert Thomas Littleton, Gillett, Wyo.
Jerry E. Upp, S. W. Lohman, Thad G. McLaughlin
Dorothy Rose Matz, Shreveport, La.
G. D. Thomas, John G. Watson, George V. Cohee
Donald Dea McGirk, Bogota, Colombia, S. A.
Walter M. Chappell, C. William Saville, W. C. Hatfield
Jack B. Mills, Bogota, Colombia, S. A.
Walter M. Chappell, W. C. Hatfield, C. William Saville
Jack Nathaniel Morehead, Fort Worth, Tex.
Sidon Harris, F. H. Schouten, R. H. Dana
William Paul Ogilvie, Calgary, Alta., Canada
John O. Galloway, J. D. Weir, J. G. Gray
Charles Knox Overton, Houston, Tex.
J. B. Garrett, Jr., Morton B. Stephenson, Albert D. Ellis, Jr.
Sidney A. Parkans, Houston, Tex.
P. B. Leavenworth, Marcus A. Hanna, H. E. Minor
Emory Wade Parrott, Abilene, Tex.
David M. Grubbs, Frank B. Conselman, William M. McGill

Jack Lee Penick, Corpus Christi, Tex.
J. P. Fox, H. L. Burchfiel, Malcolm D. Bennett, Jr.
David E. Pope, Forrest City, Ark.
R. J. Russell, H. V. Howe, H. N. Fisk
Weldon Willis Rau, Tacoma, Wash.
A. C. Trowbridge, A. K. Miller, Allen C. Tester
Wayne Alexander Ross, Houston, Tex.
Sherwood Buckstaff, H. M. Fritts, H. M. Goodman
James Edward Smyth, Corpus Christi, Tex.
Martin Matson, G. J. Smith, J. M. Vetter
Frank Payler Sonnenberg, Harrison, Ohio
Robert C. Lafferty, Edward Cramon Stanton, Jr., Alan H. McClain
Samuel Schuyler Streeter, Stanford University, Calif.
Siemon W. Muller, V. L. Vander Hoof, A. I. Levorsen
Curtis Everett Turney, Anadarko, Okla.
Charles E. Decker, F. A. Melton, Carl A. Moore
Harry Westmoreland, Antlers, Okla.
C. E. Siberts, Robert D. Sprague, Garth W. Caylor
Paul Cranston Wood, South Charleston, W. Va.
Donald L. Norling, George T. Crouse, V. C. Scott

FOR TRANSFER TO ACTIVE MEMBERSHIP

Keith Elliott Anderson, Iowa City, Iowa
Earl McCracken, A. K. Miller, Robert P. McNeal
Elizabeth Anne Elliott, Denver, Colo.
N. W. Bass, S. W. Lohman, W. J. Hilseweck
William Charles MacQuown, Jr., Oklahoma City, Okla.
Fred H. Moore, John R. Sandidge, Ira H. Cram
Albert R. Perko, Bogota, Colombia, S. A.
W. C. Hatfield, C. W. Saville, W. M. Chappell
Millicent Aloyse Renfro, Fort Worth, Tex.
C. E. Yager, R. H. Schweers, D. G. Stookey
William Eastburn Richardson, Tyler, Tex.
R. M. Trowbridge, Ray F. Youngmeyer, A. C. Wright
Wilburn Hale Seals, Jusepin, Venezuela, S. A.
Douglas D. Howard, J. H. Sawyer, Leroy E. Becker
Richard Nelson Spencer, Corpus Christi, Tex.
Robert Hendrickson, John R. Sandidge, W. W. Hammond
Warren Charles Thompson, La Jolla, Calif.
Francis P. Shepard, M. N. Bramlette, U. S. Grant
William Harry Wallace, Jr., Corpus Christi, Tex.
Donald A. Ross, C. C. Miller, O. G. McClain

(*Continued on page 2181*)

NOMINEES FOR A.A.P.G. PRESIDENT, 1949–1950

RONALD K. DEFORD

Professor of geology, University of Texas, Austin
Born, January 22, 1902, San Diego, Calif.

Academic Training

1917–22	Colorado School of Mines; E.M., 1921; Geol. M.S., 1922

Experience

1921–22	Colorado Sch. of Mines, Geol. Dept.
1922–24	Colorado Sch. of Mines, Chem. Dept.
1923–33	Midwest Refining Company
1931–33	Colorado Sch. of Mines, English Dept.
1933–48	Argo Oil Corporation
1948–	University of Texas

Publications.—Field of structure, stratigraphy, geophysics, petroleum geology

Professional Affiliation (National)
Amer. Assoc. Advancement of Science
Amer. Geophysical Union
Amer. Inst. Min. Met. Engineers
Geological Society of America

A.A.P.G. Activity

1931, 1939–41	Business Committee
1938	Chm., Tech. Program, El Paso
1938–42	Spec. Editor, W. Tex.-N. Mex. Symp.
1939–41, 46	Chm., Permian Sympos.
1940–48	Research Committee
1942–46	National Service Committee
1944–46	Com. Method of Election of Officers
1946–	Repr., Rock-Color Chart Com.
1946–48	Education Committee
1947	Ballot Committee
1947–48	Reporter to "Science on the March," in *Sci. Monthly*, A.A.A.S.

W. C. SPOONER

Consulting geologist, Shreveport, Louisiana
Born, 1880, Brooklyn, New York

Academic Training

1898	Cooper Union, New York. Civil Engineering

Experience

1900–14	Prospecting and surveying, Alaska and Mid-Continent
1915	The Texas Company, Louisiana
1916–17	Hager and Bates, Mid-Continent
1919	Hartman and Spooner, Louisiana
1920–25	Arkansas Natural Gas Company, S. Mid-Continent and Gulf Coast Benedum-Trees, South Pacific, South America, Yucatan
1926–	Consulting

Military Service

1917–18	1st Lieut., Engineers, France

Publications.—Petroleum geology

A.A.P.G. Activity

1927–	Business Committee
1927–32	Assoc. Editor
1931, 34–38	Research Committee
1947–	Medal Award Committee

C. W. TOMLINSON

Oil producer, Ardmore, Okla.
Born, April 23, 1892, Detroit, Mich.

Academic Training

1909–14	University of Wisconsin; Geol. B.A., 1913; Geol. M.A., 1914
1914–15	University of Minnesota
1915–16	Univ. Chicago; Geol. Ph.D., 1916

Experience

1916	Carter Oil Company
1916–17	Miss. State College, Prof., Geol.
1917–18	Univ. Illinois, Assoc., Geol.
1918–21	Gulf Oil Corporation
1921–36	Schermerhorn Oil Corporation
1936–	Consultant and Producer

Publications.—Stratigraphic, structural and petroleum geology

Professional Affiliation (National)
Amer. Assoc. Advancement of Science
Amer. Geographical Society
Amer. Inst. Min. Met. Engineers
Geological Society of America

A.A.P.G. Activity

1936–38	Research Committee
1939–41; 47–48	Business Committee
1939–46	Geol. Names and Cor. Com.
1943–45	Comm. Classif. Nomenclature Rock Units (Chm., 1945)
1944	Code of Ethics (Chm.)

FOR VICE-PRESIDENT, 1949–1950

THEODORE A. LINK

Consulting geologist, Toronto, Ontario
Born, Jan. 19, 1897, Laporte, Indiana

Academic Training
1915–18 Univ. Chicago; Geol., B.Sc.
1926–27 Univ. Chicago; Geol., Ph.D.

Experience
1918 Geological Survey of Canada
1918–19 Empire Gas and Fuel Co.
1919–22 Imperial Oil Ltd.
1922–26 Tropical Oil Co.
1927–48 Imperial Oil Ltd.
1948– Consulting geologist

Publications.—Structural and stratigraphic geology

Professional Affiliations (National)
Amer. Assoc. Advancement of Science
Amer. Geophysical Union
Amer. Inst. Min. Met. Engineers
Geological Association of Canada
Geological Society of America

A.A.P.G. Activity
1930; 32–36; 41–42; 48 (Chm.) Bus. Com.
1935– Associate Editor
1936–38 Research Com.

FOR EDITOR, 1949–1950

ALFRED H. BELL

Geologist and head, Oil and Gas Div., Illinois State Geol. Survey, Urbana
Born, June 28, 1895, Simcoe, Ontario

Academic Training
1912–15 Univ. Toronto
1917 Chem. and Min., B.A.
1920–21 Univ. Toronto
1921–24 Univ. Chicago
1926– Geol., Ph.D.

Experience
1914; 1920–23 Canada Geol. Survey
1924–26 The Texas Company
1926– Illinois State Geol. Survey

Military Service.—Canadian Overseas Expeditionary Force, 1916–19

Publications.—General geology and petroleum geology

Professional Affiliation (National)
Amer. Assoc. Advancement of Science
Amer. Geophys. Union
Amer. Inst. Min. Met. Engineers
Geological Society of America
Sigma Xi
Research and Co-ord. Com., Interstate Oil Compact Comm.

A.A.P.G. Activity
1940 Chm., Program Com. Ann. Meeting
1940–41 Business Committee
1942–44 Committee for Publication
1943–46 Research Committee
1945–50 Com. Statistics Explor. Drilling
1947–50 Medal Award Committee

KENNETH K. LANDES

Professor and chairman, Dept. Geol., Univ. Michigan, Ann Arbor
Born, May 10, 1899, Seattle, Wash.

Academic Training
1917–21 Univ. Washington, B.S., 1921
1921–25 Harvard Univ., A.M., 1923; Ph.D., 1925

Experience
1926–41 Univ. Kansas; Kansas Geol. Survey
1941– University of Michigan
1921– U. S. Geol. Survey (intermittently)

Publications.—Field of mineralogy, economic geology, and subsurface stratigraphy

Professional Affiliation (National)
American Assoc. Advancement of Science
American Geophysical Union
Geological Society of America (Vice-Pres., 46)
Mineralogical Society of America (Pres., 45)
Society Economic Geologists

A.A.P.G. Activity
1940–44 Com. on College Curricula
1944–48 Com. Applic. Geology (Chm., 1946–48)

FOR SECRETARY-TREASURER, 1949–1950

FRED H. MOORE

District geologist, Magnolia Petroleum Co., Roswell, New Mex.
Born, November 2, 1909, Comanche, Tex.

Academic Training
1926–30 Texas Tech. College; Geol., B.A.
1930–31 Univ. Virginia; Geol., M.A.
1931–33 Yale Univ.; Geol., Grad. Student

Experience
1931–33 Connecticut Geol. Nat. Hist. Survey
1933–35 Geologist, U. S. Gypsum Co.
1935– Magnolia Petroleum Co.

Publications.—Economic Study of Limestones and Dolomites of Connecticut (*Conn. Geol. Nat. Hist. Survey Bull. 56*)

Professional Affiliation (National)
American Geophysical Union

A.A.P.G. Activity
1944–48 Distinguished Lecture Com. (Chm., 45–48)

E. E. REHN

Division geologist, Eastern Div., Sohio Petroleum Co., Evansville, Ind
Born, Dec. 27, 1915, Ochelata, Okla.

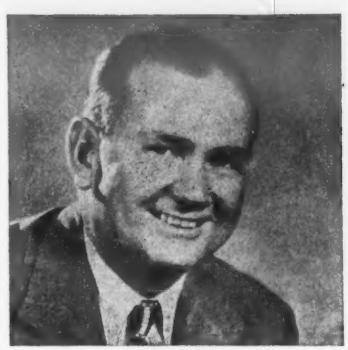
Academic Training
1935–36 Kansas State College, Mech. Eng.
1937–40 Univ. Wichita, Geol., B.S., 1940
1940–42 Ohio State Univ., Grad. Asst., Geol. M.S., 1942

Experience
1938–40 Magnolia Petroleum Company
1942– Sohio Petroleum Company

Publications.—Stratigraphy in Appalachian area

Professional Affiliation (National)
American Inst. Min. Met. Engineers

A.A.P.G. Activity
1948–49 Business Committee
1948–49 Publications Committee



HENRY N. TOLER

Manager, Geol. and Land Dept., Southern Natural Gas Co., Jackson, Miss.
Born, Oct. 24, 1902, French Camp, Miss.

Academic Training
1921–25 Louisiana State Univ.; Geol. B.S., 1925
1926–29 Univ. Illinois; Geol. M.S., 1929

Experience
1926 Illinois Geological Survey
1927–28 The Texas Co., Colombia, S. A.
1929–31 Gulf Refining Company
1931–36 Consultant and Asst. Miss. State Oil and Gas Supervisor
1936–38 Miss. State Oil and Gas Supervisor
1938– Southern Natural Gas Company

Publications.—Field of petroleum geology

A.A.P.G. Activity
1942–43 Committee for Publication
1945 National Service Committee
1946–48 Business Committee
1946– Associate Editor

PITTSBURGH REGIONAL MEETING, OCTOBER 4–9

The regional meeting of the Association at Pittsburgh, Pennsylvania (September *Bulletin*, pp. 1844–46) attracted an attendance of 250 geologists at the program sessions in the William Penn Hotel and 100 on the 4-day field trip across Pennsylvania and New York. Copies of the 121-page, profusely illustrated guidebook, prepared by the Pittsburgh Geological Society, are available at $5.00 per copy, by writing Geo. C. Grow, Jr., 545 William Penn Place, Pittsburgh 19, Pennsylvania.

Abstracts of Pittsburgh Papers

1. "General Orientation: Review of Geology of Appalachian Area," *by R. E. Sherrill.*

This paper reviews the general geology of the Appalachian basin for a better understanding of the remaining papers on the program and of the field trip. Particular attention is directed to the types of accumulation now known to prevail in the older fields and to the stratigraphic and structural problems in the search for new production.

2. "Petrology and Paleogeology of Greenbrier Limestone," *by Gordon Rittenhouse.*

This paper outlines the petrology and paleogeography of the Greenbrier formation of Mississippian age, as determined from study of well samples, insoluble residues, heavy minerals, and thin sections. In the Greenbrier, clastic limestone beds composed of calcareous sand, oölites, and quartz sand alternate with beds of fine-grained limestone in which clastic texture is indistinct or can not be recognized. The clastic limestones appear to be near-shore sediments and in part probably are ancient bar, beach, channel, and dune deposits and have the shapes and trends characteristic of such deposits. About half of the production of oil and gas from the Greenbrier is from clastic limestones; about half from dolomite and dolomitic limestone.

Dolomite and dolomitic limestones are largely confined to the basal 20–30 feet of the formation. This basal zone appears to transgress both structure and time units. The dolomite clearly replaces limestone. Four methods by which magnesium-bearing waters could be introduced into the formation are suggested and the probable pattern of dolomitization resulting from each method is considered.

The quartz sand in the Greenbrier was derived from two or more different sedimentary sources on the north. Earlier Mississippian and Upper Devonian sands of West Virginia, Ohio, and Pennsylvania were not important sources of the quartz sand.

3. "Hemlock Grove Oil Field," *by R. L. Alkire.*

Two factors have seriously handicapped the presentation of this review. One is the lack of a thorough understanding of the nature of oil accumulation in the Berea sand and the other is the unavailability of sand data and production statistics within the field. Several cores have been taken but the results of their analysis have not been released. In the absence of such information this paper is confined to a historical review leading to the discovery well, the field development, and finally a limted discussion of the Berea sand.

4. "Geology of McDonald and Adjacent Oil Fields, Allegheny and Washington Counties, Pennsylvania," *by A. I. Ingham.*

The McDonald, Venice, McCurdy, and Moon Run oil fields form a producing area 15 miles long by 1–4 miles in width, located in southwest Allegheny and north Washington counties, Pennsylvania. Regionally the area is in the western part of the Appalachian foreland, and approximately 5 miles west of the axis of the Pittsburgh-Huntington synclinorium.

Development in the area took place largely during the period 1890–1900. The McDonald field, one of the largest and most prolific in the Appalachian basin, was discovered in 1891. Two wells in the field each had an initial production variously estimated at 14,000–17,000 barrels per day. In late 1891, McDonald was producing 1,800,000 barrels per month. Cumulative production of all the fields to the middle of 1909 totalled 42,135,000 barrels.

The Wildwood anticline and Mt. Nebo syncline, northeast-southwest trending structures, pass through the fields. Approximately perpendicular to these two structures, and limiting them on the south, is the Cross Creek syncline. Minor structural features are common. Regional dip is south and southeast into the Nineveh and Cross Creek synclines.

Oil is produced principally from Conewango sands of Upper Devonian age—One Hundred foot, Fifty foot, Lower Nineveh, Gordon Stray, Gordon, Fourth and Fifth sands—the last three producing most of the oil.

The fields are typical of the stratigraphic-trap type, oil accumulation in the various pools being

controlled by the lenticular and lithologic character of the sands. Some structural control is indicated. Gas is found in the structurally higher parts of the sands.

5. "Geology and Occurrence of Natural Gas in Oriskany in Faulted Anticlines with Particular Reference to Northern Pennsylvania and Southern New York Producing Area," *by F. H. Finn.*

The Oriskany sandstone, which has been important as a source of natural gas in the Appalachian area, has been productive in 66 different pools throughout the Appalachian area. Many of the pools are small, and some of them were discovered many years ago when the Oriskany was not recognized as the producing formation. Most of the pools have resulted from structural trapping, although more than half of the total reserve of gas has been found in a large pool in West Virginia which is productive chiefly because of an interruption in porosity in an updip direction. Over 1½ trillion cubic feet of gas reserves have been discovered in the Oriskany since 1930.

In northern Pennsylvania and southern New York a producing province including 34 pools has been developed between 1930 and the present. Practically all of these pools result from structural traps caused by doming and thrust faulting along a series of prominent anticlines.

The province is described and a structure map of the area is presented. One of the most prominent producing trends (the Hebron-Harrison-Woodhull area), involving a complicated faulting pattern and the merging of two anticlines, is described in detail by means of surface and subsurface structure maps and cross sections.

6. "Structural Accumulation of Natural Gas in Oriskany Sand of Tri-State Area," *by John T. Galey.*

In the Tri-State area, comprising east-central Ohio, southwestern Pennsylvania and northern West Virginia, between the highly folded structures (Chestnut Ridge anticline) on the east, and the area in which the Oriskany sand becomes patchy in its distribution on the west, seven gas pools have been found in the Oriskany sand on low-relief domes. The history of discovery, stratigraphy, structure of the surface rocks, structure of the Berea sand, convergence between the Berea and Oriskany sands, and structure on the Oriskany sand, together with development, operation, and reservoir data, are discussed for the three most important of these pools, which are Blackhawk, located in South Beaver Township, Beaver County, Pennsylvania, and the Knox and Round Knob located in Knox and Madison townships, Columbiana County, Ohio, respectively.

7. "Oriskany Sand in Ohio," *by J. R. Lockett.*

The Oriskany is a somewhat regular sand body in an area comprising parts of fourteen counties in eastern Ohio. The western limit of this consistent deposit can be plotted as a very irregular line between Trumbull and Meigs counties. Although relatively large lenses of sandstone have been encountered at this horizon as far west as Knox County in the central part of the state, only two small fields have been discovered in western outliers.

The Cambridge field, discovered in 1922, was developed along the western pinch-out of the Oriskany in a typical stratigraphic trap extending from southwestern Guernsey County into south-central Tuscarawas County. The sand was absent west of the field, oil has accumulated immediately below the gas and a definite water horizon was encountered on the normal southeast dip below the oil at a depth of 2,600 feet below sea level. Although hard and sharp, the sand was exceptionally open in texture. Virgin rock pressure was 1,150 pounds. Gas wells were large in volume but relatively short lived. At its peak in 1926 the field produced 190,000 MCF per day.

During 1935 a small gas field with a virgin pressure in excess of 1,600 pounds was discovered on a closed structure in Madison and Wayne townships, Columbiana County, at an average depth of 3250 feet below sea level. The few wells drilled were soon ruined by water and the field was of no commercial importance. During 1946 a gas field was developed on a similar structure and at approximately the same depth a few miles east in Madison Township. High pressures and large initial volumes encouraged development but water encroachment ruined these wells within a year. These two small gas fields are the only producing areas developed in Ohio where accumulation in the Oriskany sand was definitely controlled by anticlinal structure.

In 1944 a gas field was discovered along the western limit of the Oriskany in eastern Knox Township, Columbiana County, at an average depth of 2,400 feet below sea level. Initial rock pressures were in excess of 1,300 pounds. Although no oil was discovered downdip, high permeability of the sand and large initial volumes of the wells indicate that their history will be comparable with that of the Cambridge field.

A gas well with an open flow capacity of 2,500 MCF was recently completed at a depth of approximately 2,100 feet below sea level near the Pennsylvania line in Vernon Township, Trumbull County. It is one location west of two small oil wells which are located immediately up the normal dip from

FIG. 1.—General chairman Hugh R. Brankstone welcoming geologists to A.A.P.G. regional meeting at Pittsburgh, Pennsylvania, October 4, in Urban Room of William Penn Hotel.

FIG. 2.—At registration desk, Silver Room.

FIG. 3.—Donald L. Norling, holding field-trip guide-book; Hugh R. Brankstone, general chairman; John T. Galey, president, Pittsburgh Geological Society.

FIG. 4.—At technical session: John F. Hosterman, James L. Tatum (standing), Paul Weaver, John L. Ferguson.

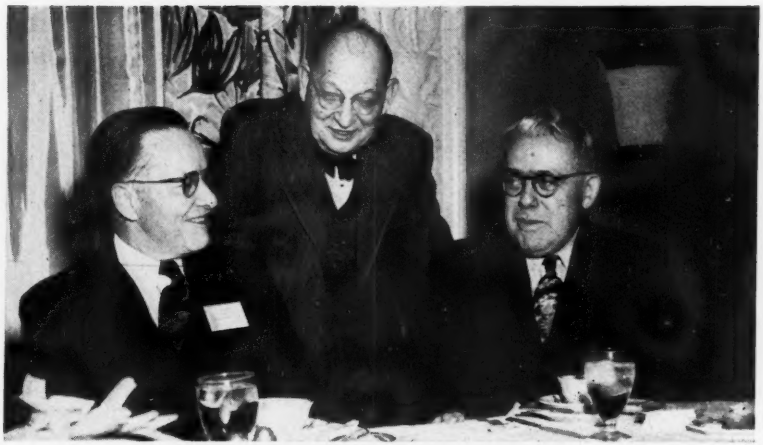


FIG. 5.—At banquet: Clarence L. Moody, Paul Weaver, J. V. Howell.

FIG. 6.—Speakers' table, at banquet: E. R. Weidlein, director, Mellon Institute of Industrial Research, and Kenneth C. Heald, vice-president, Gulf Oil Corporation.

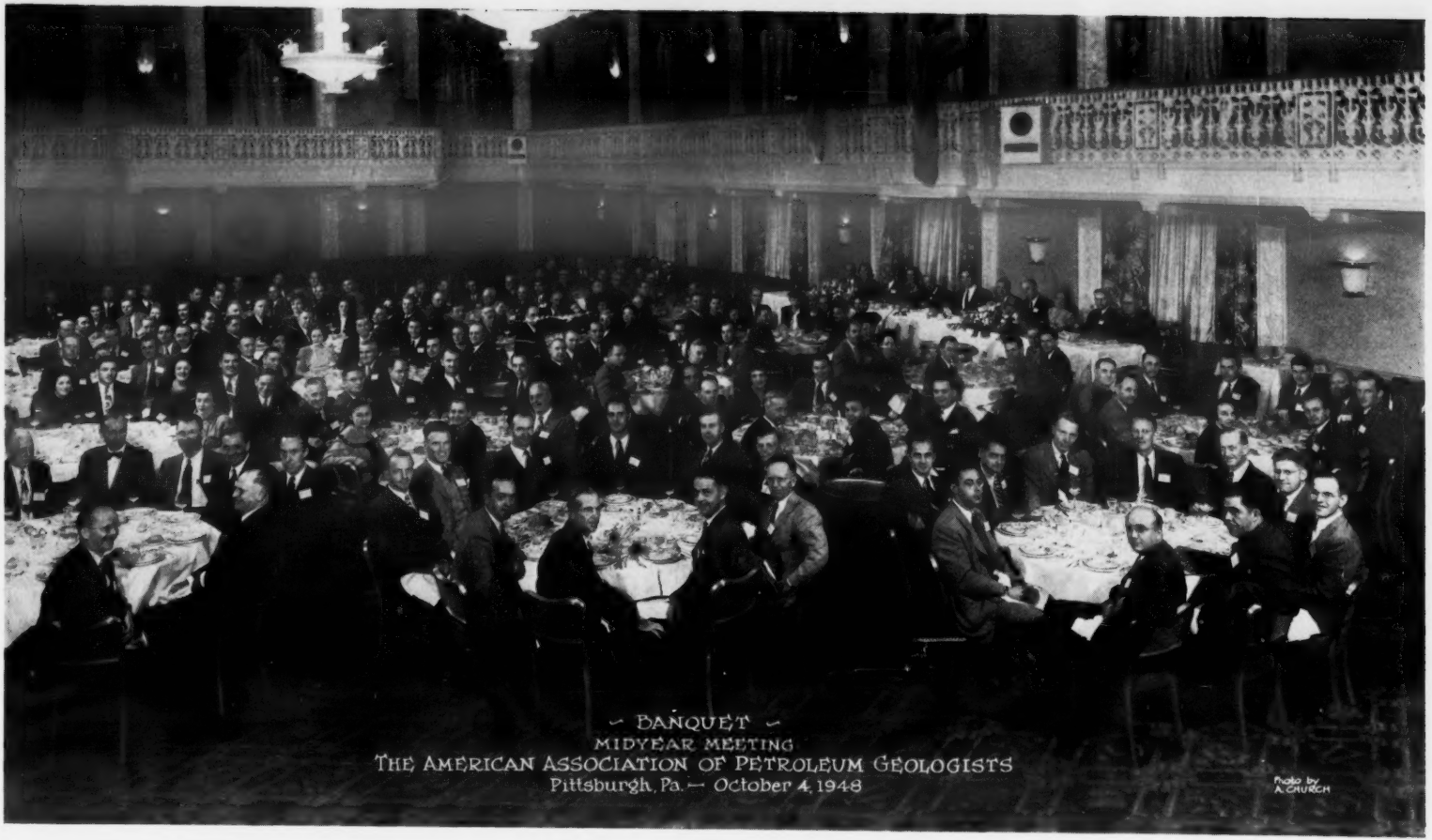


FIG. 7.—Banquet, William Penn Hotel, October 4.

four dry holes completed in water bearing Oriskany sand. These tests are located within a distance of one mile east and west and indicate the possibility of a stratigraphic trap along the western limit of the sand in that area.

The position of the Oriskany sand in the series of Devonian and Silurian limestones and dolomites called the "Big Lime" and its possible correlation with the Austinburg sand in Ashtabula County are discussed.

8. "Kanawha-Jackson Oriskany Gas Field," *by A. H. McClain.*

The Kanawha-Jackson Oriskany Gas Field is in Kanawha and Jackson counties, West Virginia. The main pool extends north from Charleston in a broad tapering belt 15 miles wide at Sissonville and 2 miles wide in northern Jackson County. The Blue Creek pool is 8–12 miles above Charleston in a band 4 miles long and 3 miles wide. The Boone County-Campbells Creek pool is on the Warfield anticline 6 miles south of Charleston in a belt 12 miles long and 3 miles wide. On January 1, 1948, the total area was 193,000 acres and the total gas produced was 721,482,555 MCF. At that time 1,239 wells had been completed to the sand, of which 1,076 were saved as gas wells and 163 were dry holes. The 1,076 gas wells have produced an average of 737,269 MCF per well. It is estimated that the field is 75–80 per cent depleted, and that the ultimate production will be 910,000,000 MCF, an average of 4,715,000 MCF per acre.

9. "Mayfield Pool, Cuyahoga County, Ohio," *by Howard E. Rothrock.*

The Mayfield gas pool, most prolific Newburg "sand" pool in Ohio, is in northeastern Cuyahoga County. The rocks that have been tested by drilling range from Upper Ordovician to Upper Devonian. Outcrops include rocks of Upper Devonian and Mississippian age. They are extensively covered by Pleistocene and Recent deposits. Gas and a small amount of oil is obtained from the Newburg "sand" (Middle Silurian) at an average depth of 2,875 feet, and from the Oriskany sand (Lower Devonian) at a depth of about 1,800 feet. The reservoir is of the structural type in the Oriskany sand and of a combined structural and porosity type in the Newburg "sand." The structure is incompletely outlined because of Pleistocene cover at the surface and restrictions on drilling south and southwest of the pool. At the surface it is dome-like with limbs dipping about 0°–18′. In the subsurface it appears to be a broad anticline trending northeast with a known closure of approximately 100 feet. Its southeast limb dips about 0°–38′. Fifty-two tests, eleven of which were dry holes, have been drilled on the anticline. The total yield of gas, as of December 31, 1947, has been about 13¼ billion cubic feet from wells showing a distribution ratio of 30 acres per well. The chances of obtaining oil or gas from deeper Ordovician and sub-Ordovician strata are considered to be chiefly dependent on the amount of closure that occurs in the structure in these deeper strata, and on the porosity of the rocks.

10. "Philosophy of Research," *by E. R. Weidlein, Director, Mellon Institute of Industrial Research.*

Banquet address.

11. "Salina-Guelph Fields of Southwestern Ontario," *by W. A. Roliff.*

The dolomites of the lower part of the Salina formation and the upper part of the Guelph-Lockport formations, of Silurian age, comprise the most important and most prolific gas-productive zone in southwestern Ontario, total production to date amounting to 275 billion cubic feet. This zone has also yielded 1,500,000 barrels of oil. Commercial production was first obtained in the Salina-Guelph zone in the year 1889, and by 1906 the two most important Salina-Guelph fields in the Province had been discovered. Subsequent exploration has been very sporadic, and although eight relatively moderate-sized pools have been discovered, 10,000 square miles, or 80 per cent, of the area underlain by these formations remains relatively untested.

Folding and faulting appear to be the dominant factors controlling accumulation, but reefs, variations in porosity and incipient fracturing seem to be almost equally important.

This paper describes the geological conditions affecting accumulation and the recently renewed efforts to find additional pools in this zone, and briefly discusses the prospects for future discoveries.

12. "Geology and Occurrence of Oil in Medina Sand of Blue Rock-Salt Creek Pool, Ohio," *by James F. Swain.*

13. "Rose Hill Oil Field, Lee County, Virginia," *by Byron N. Cooper.*

Commercial production of high-gravity paraffine-base oil from Middle Ordovician limestones beneath the Pine Mountain overthrust block was initiated in 1942 in the Fourmile Window near Ewing, Lee County, Virginia. Drilling activities since May, 1946, have been sufficiently successful to

arouse national interest in the field. In January, 1947, production was extended into the Martin Creek Window, 4 miles northeast of the discovery wells on Fourmile Creek. Some oil has since been obtained from the intervening area, and some of the successful wells have penetrated thin remnants of the overthrust block. Drilling activities, "shooting," and acidizing work are summarized. The stratigraphic characteristics of the field and the evolution of the trapping structures are discussed with particular reference to the manner of accumulation and other fundamental problems.

14. "Regional Aspects of Cambrian and Ordovician Subsurface Stratigraphy in Kentucky," *by Louise Barton Freeman.*

Suggestions are made for correlation of Cambrian penetrated in the deeper wells in Kentucky with the outcrop on the Ozark uplift and with the sections on the north. Thickness maps indicate (1) the overlap of older Knox formations by younger members of the Chazyan on the north, and (2) the unconformity at the top of the Cincinnatian with loss of younger formations toward the Ozark uplift.

Facies maps are used to indicate lithologic changes through the major divisions of the Ordovician. The pattern of these facies suggests that an extended Ozark uplift was source for much of the clastic sediments from Chazy to the close of the Cincinnatian. A sub-Cretaceous areal geologic map is presented to show the probable extent of the old uplift.

15. "Late Ordovician and Silurian Facies, Conditions of Deposition and Paleogeography in North-Central Appalachians," *by Frank M. Swartz.*

The Late Ordovician and Silurian sediments of the north-central Appalachians consist dominantly of detritals, their maximum thickness about one mile, swept from land surfaces on the east into a broad geosynclinal area.

Three great detrital complexes reflect diastrophic-paleogeographic activities; they are formed by Bald Eagle-Oswego-Juniata-Queenston sediments; the Shawangunk-Tuscarora-Medina-Clinton-McKenzie sediments; the Bloomsburg-Vernon-Wills Creek-Camillus sediments. Carbonates are significant in the McKenzie limestone and shale and Lockport dolomite above the Clinton shales, and at higher levels are more widespread in the Tonoloway and Keyser limestones and their equivalents.

Each of the three great detrital complexes attains its greatest thickness in Pennsylvania. The sedimentary maximum for the Bald Eagle-Oswego-Juniata-Queenston deposits is located in central Pennsylvania; maxima for the Shawangunk-Tuscarora-Medina-Clinton and Bloomsburg-Verona-Wills Creek-Camillus are shifted farther east. It is suggested that location of these maxima reflects the area of debouchment of an ancient major river system that drained from the Old-land Appalachian across the present region of northern New Jersey.

The Late Ordovician Juniata-Bald Eagle sediments consist of poorly winnowed sand and silt detritals coarsening toward and north of Harrisburg to puddingstones with 3- to 6-inch pebbles of vein quartz, vitreous quartzites, meta-argillites, cherts. The Bald Eagle and Juniata are eastwardly equivalents of Maysville-Richmond marine shales and limestones of Ohio, but themselves lack fossils; they were deposited rapidly in freshened waters, perhaps in part directly on alluvial surfaces, in part in extensive lagoonal-estuarine regions. The Middle Silurian Clinton and McKenzie sediments contain profuse marine faunas; sedimentation as compared to evolution was long enough continued, and there are finely developed evolutionary faunal zones as well as intriguing facies problems. The Tuscarora sandstone below the Clinton, and the Shawangunk conglomerate that replaces both Tuscarora and Clinton on the east, contain some eurypterids, and were deposited in part in shallow freshened seas where winnowing of quartz sands was active and effective, in part on the east on or near alluvial areas where gravelly, somewhat graywackyish sands are present. The Bloomsburg redbeds are nonfossiliferous. On the whole they are presumed to be alluvial; but extensive fine-grained sandstone members in the thinned western parts indicate active spreading in shallow bodies of water. The Bloomsburg red sediments grade westward into upper McKenzie and Wills Creek clayey deposits, and into lower beds of the Tonoloway limestone. Widespread Upper Silurian salt deposits are equivalent in age to parts of the Bloomsburg redbeds, but not co-extensive with them.

In the Late Silurian, marine advances culminated in sedimentation of the Tonoloway and Keyser limestones. The Keyser seaways had good oceanic connections both north and south, and in them flourished extensive and diagnostic, progressively changing assemblages of brachiopods, corals, bryozoans, and ostracods, that are excellent for correlation. Waters well connected with the oceans and favorable for profuse marine life, persisted along much of the Appalachian region during Lower Devonian Helderbergian and Oriskany sedimentation; at times these waters were clear over large areas; elsewhere and at other times well winnowed sands and clays accumulated slowly over the sea floor.

In their northwesterly subsurface extensions, gas has been extensively produced from the Lower Silurian Tuscarora-White Medina and Lower Devonian Oriskany sands: some production has come from Middle Silurian Lockport equivalents of the McKenzie formation; the Late Ordovician Bald Eagle-Oswego sands may have reservoir possibilities.

16. "Results of Studies of Ordovician Rocks East of Allegheny Front in Pennsylvania," *by C. E. Prouty.*

The Ordovician rocks adjacent to the Allegheny Front consist of 6,500 feet of limestones, dolomites, and shales. The rocks become increasingly clastic upward, reflecting the growing movement that culminated in late Ordovician orogeny on the southeast. The Lower Ordovician consists of 2,775 feet of dolomite with two relatively thin limestone members. The homogenous lithology does not permit as detailed zoning as middle Ordovician limestones. However, a few lithic and faunal zones persist over fairly wide areas and are useful as mapping units. Some units may be helpful in subsurface geology in the adjacent Allegheny Plateau area. Middle Ordovician rocks, 1,375 feet thick, are divided into 15 major units which may be subdivided. Upper Ordovician clastics, 2,350 feet thick, consist largely of thick shales, claystones, siltstones, and sandstones which are not readily subdivided into characteristic zones.

Favorable reservoir rock in the Ordovician is limited. However, coarse calcarenites of the Trenton and Black River may offer some promise. The foetid odor of hydrocarbons is noticeable throughout much of the Ordovician, especially in some of the clastic limestones. Coarse-grained limestones and dolomites are generally darker than the denser carbonates, the darkness of color roughly proportional to increasing grain size. The relationship of the hydrocarbon content to grain size in these rocks deserves further study. Beekmantown and Upper Cambrian dolomites show small carbonate-lined cavities having foetid odor, a few showing oil stains. The Upper Cambrian Gatesburg contains numerous coarse sandstone beds which probably offer better potential reservoir rock than Ordovician units.

Several conclusions regarding the nature of the Ordovician rocks beneath the Allegheny Plateau may be based on outcrop data and paleogeographic probabilities. Gatesburg sandstones likely thicken and coarsen westward beneath the plateau. The Beekmantown dolomite probably thickens for a short distance beneath the plateau, with the limestone phases becoming more dolomitic. The Chazy probably thins and disappears in the central plateau area. Lower Black River units thin while upper Black River units thicken beneath the plateau for a short distance. Most Middle Ordovician units become more magnesian westward beneath the plateau. Upper Ordovician units become less clastic and thin westward.

17. "Subsurface Upper Devonian Sections in Southwestern Pennsylvania," *by R. E. Bayles.*

With the exception of small inlier areas along the axes of Chestnut Ridge and Laurel Ridge anticlines, the Upper Devonian rocks of southwestern Pennsylvania are concealed beneath a mantle of Mississippian, Pennsylvanian, and Permian sediments. Thus, the study of this very important group of rocks becomes a problem for the subsurface stratigrapher over a third of the surface area of Pennsylvania. Drilling, in recent years, along Chestnut Ridge and Laurel Ridge anticlines, and also in the broad plateau area between Laurel Ridge and the Allegheny Front, has yielded many excellent sections based on detailed examinations of drill cuttings. Some of these sections, in a generalized graphic form, together with additional ones located in the oil- and gas-producing area west of Chestnut Ridge, are assembled into cross sections which illustrate the facies variations in the Upper Devonian sediments of southwestern Pennsylvania. The Conewango (uppermost Upper Devonian) age of the Devonian rocks exposed in the inlier areas of Chestnut Ridge and Laurel Ridge anticlines is confirmed. With the exception of the Huntersville chert and Oriskany sandstone, which are Lower Devonian in age, the producing sands of southwestern Pennsylvania all appear to be younger than the highest sub-Catskill marine beds exposed along the Allegheny Front, which are generally considered as being late Chemung in age.

18. "Aerial Magnetic Survey of Appalachian Plateau in Central Pennsylvania," *by H. R. Joesting, F. Keller, and E. King.*

The aeromagnetic map of central Pennsylvania, covering 1,800 square miles, is dominated by two large positive anomalies which apparently originate within the deep-lying crystalline rocks. Minor magnetic irregularities also occur, and these are attributed to shallower sources.

In the comparatively small area under consideration, the anomalies are essentially unrelated in position and form to the sedimentary structures which trend northeast-southwest. Their probable causes are discussed and estimates of their depth of origin are made.

19. "Evolution of Thought on Structure of Middle and Southern Appalachians," *by John Rodgers.*

The first men to comprehend the structure of the Appalachian Mountains were the brothers, Henry D. and William B. Rogers, who from 1835 to 1842 studied them from northern New Jersey

to southwest Virginia. They worked out the Paleozoic stratigraphy of the area and by means of it deciphered the folds of the middle Appalachians and the thrust faults of the southern Appalachians. They attempted to explain the structure as the result of great explosions on the southeast but, beginning with Dana, geologists have come to ascribe the structure to lateral compression.

Since the time of the Rogers brothers, many structural ideas have emerged from the study of the Appalachians, such as the geosyncline, underthrusting, erosion thrusts, the competence of strata. Prominent among the many investigators was the group of geologists headed by Willis and Hayes who, late in the nineteenth century, worked out several of the low-angle large-displacement thrust faults of the southern Appalachians and attempted to explain the mechanics of Appalachian structure.

In recent years there have been developing two schools of thought on the depth of Appalachian deformation. One school holds that all large folds and faults extend down to and are supported by the basement; the other holds that the deformed rocks have been stripped completely off the basement along one or more great bedding-plane thrust faults.

20. "Structures of Basement Rocks of Pennsylvania and Maryland and Their Effect on Overlying Structures," *by Ernst Cloos.*

The folded Appalachians are paralleled by an eastern "hinterland" of intensely dislocated and metamorphosed crystalline rocks. Fossils have not been found and the area has not been studied in as much detail as is desirable. This is due to its seemingly hopeless composition of uniformly crystalline rocks, poor exposures and the great attraction exerted by better exposures and more spectacular geologic objects farther west.

The age of the crystallines is largely undetermined and they may be either basement of the appalachian geosyncline and its folds or their highly deformed crystalline axis. Some of the crystallines—the Baltimore gneiss and its equivalents—seem to be pre-Cambrian but most of the overlying metamorphics probably belong to the crystalline axis and the lower Paleozoics. The pressing problem is the determination of age relationship and thus the extent of what may be called a basement.

If a preliminary division of the crystalline axis into a basement and an overlying metamorphic series is accepted it is readily seen that the trends of the crystallines above deviate from those of the basement below. The gneiss appears in elongate and well defined uplifts of limited size and generally showing dominating vertical components whereas the schists seem to have moved forward and were possibly thrust over less metamorphosed Paleozoics following the general Appalachian trends.

There is no major break and no unconformity between the fossiliferous Paleozoics and the schist but a gradual southeastward increase of the intensity of metamorphism. The parallelism of structures is striking.

Appalachian folds within the crystalline axis are generally overturned northwestward but at numerous places virgation is southeastward.

The crystalline axis exerts a very strong influence on the overlying folds. Cleavage dominates, folds are overturned uniformly and this domination reaches as high as the Ordovician in some parts of the lower Paleozoic section. Farther away from the axis this influence declines and folding becomes more symmetrical, less uniform and at many places locally influenced by individual folds and their elements.

21. "Geological Factors Involved in Secondary Recovery," *by Maynard M. Stephens.*

Appalachian Basin Guide-Book

Copies of the Guide-Book to the Geology of the Northern Portion of the Appalachian Basin are now available. The book contains a detailed road log of the field trip of the Mid-Year Meeting of the A.A.P.G., October 6–9, 1948. It contains, besides 58 pages of road log, a special paper by Frank M. Swartz on the general character of the Paleozoic sediments of the area, an oil and gas map, relief map, structure sections, topographic sheets, geologic map, structure index map, six columnar sections for various parts of the region, oil and gas production curves, and eight glacial maps of New York state. Its size is 8½×11 inches, with leatherette cover and wire-o binding.

The price of this 121-page Guide-Book is $5.00, and copies may be secured by writing to Geo. C. Grow, Jr., 545 William Penn Place, Pittsburgh 19, Pennsylvania. Orders should be accompanied by remittance, and checks should be made payable to Pittsburgh Geological Society.

NOTE.—*A scholarly presentation of Appalachian geology; a guide to geology along the famous Pennsylvania Turnpike, the Susquehanna River, and type localities in New York; a valuable book for field students and college classes, as well as practicing geologists.*

(The following is a COPY of the announcement mailed to all members)

ANNOUNCEMENT

REGIONAL MEETING OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Rice Hotel, Houston, Texas, December 2–3, 1948

A regional meeting of the American Association of Petroleum Geologists will be held at the Rice Hotel, Houston, Texas, on December 2 and 3, 1948.

For your convenience in making hotel reservations for the coming regional meeting of the American Association of Petroleum Geologists, in Houston, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second, and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if your request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED MUST BE INCLUDED.

Hotel	*One Person*	*Two Persons*		*2-Room Suites*
		Double Bed	*Twin Beds*	*Parlor and Bedroom*
RICE	$4.00 to $7.00	$5.00 to $8.00	$6.00 to $9.00	$15.00
LAMAR	$3.50 to $5.00	$5.00 to $7.00	$6.00 & $7.00	$12.00 to $15.00
BEN MILAM	$3.00 to $6.00	$4.00 to $8.00		
SAM HOUSTON	$2.25 to $3.50	$3.25 to $4.50		
WM. PENN	$2.75 to $4.25	$4.25 to $5.75		
TEXAS STATE	$3.00 to $9.00	$5.50 & up		

In the event that the hotel room-rate structure is changed prior to the meeting these rates will be changed accordingly.

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ALL RESERVATIONS MUST BE RECEIVED BY NOVEMBER 15, 1948.

American Association of Petroleum Geologists, Hotel Reservations, Bruce Carter, Rice Hotel, Houston, Texas.

Please reserve the following accommodations for the regional meeting of the A.A.P.G. in Houston, Texas, on December 2 and 3, 1948.

Single Room..... Double-Bedded Room..... Twin-Bedded Room.....

2-Room Suite..... Other Type of Room.....

Rate: From $..... to $.....First choice hotel.....

Second choice hotel.....

Third choice hotel.....

Arriving at Hotel (date)..... Hour .....A.M.....P.M.....

Leaving Hotel (date) ..... Hour .....A.M.....P.M.....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin-bedded room requested. Names and addresses of all persons for whom your are requesting reservations and who will occupy the rooms asked for:

.....

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(Individual requesting reservations)

Name..... Address..... City & State.....

If the hotel of your choice is unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere provided all hotel rooms have not been taken.

REGIONAL MEETING

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
HOUSTON, TEXAS, DECEMBER 2–3, 1948

RICE HOTEL—HEADQUARTERS

A regional meeting of the American Association of Petroleum Geologists will be held in Houston, Texas, December 2 and 3, 1948. Members of the Houston Geological Society, which is the host society, are endeavoring to provide an attractive technical session.

Theme.—The general theme of the meeting will be "Stratigraphy, Sedimentation, and Tectonics of the Salt-Dome Region of the Gulf Coast."

Hotel reservations.—Hotel reservation forms have been published in the September and October *Bulletin*, and should have been filled in detail and promptly returned before November 15, to Bruce Carter of the Rice Hotel, headquarters hotel.

Costs.—The registration fee for A.A.P.G. members is $2.50. Students, $1.00. Ladies' style-show luncheon, $1.75. Geologists' noon luncheon, $2.00. Dance, $3.50.

GENERAL OUTLINE OF PROGRAM

WEDNESDAY, DEC. 1—2:00 P.M.–9:00 P.M.
Registration, Mezzanine, Rice Hotel

THURSDAY, DEC. 2—8:00 A.M.–9:30 A.M.
Registration, Mezzanine, Rice Hotel

8:00 A.M.–9:00 A.M.
Breakfast for authors of papers, South American Room, Rice Hotel

9:30 A.M.–5:00 P.M.
Technical Session, Crystal Ballroom, Rice Hotel

6:00 P.M.–8:00 P.M.
Cocktail party by Schlumberger Well Surveying Corporation at Houston Club

FRIDAY, DEC. 3—9:00 A.M.–5:30 P.M.
Technical Session, Crystal Ballroom, Rice Hotel

12:30 P.M.
Ladies' luncheon, style show by Sakowitz Brothers in Empire Room of Rice Hotel

12:30 P.M.
Geologists' luncheon, non-technical entertainment, Crystal Ballroom, Rice Hotel

8:30 P.M.–12:00 A.M.
Semi-formal dance, Crystal Ballroom, Rice Hotel

Films of special interest will be shown during technical sessions

TENTATIVE PROGRAM OF TECHNICAL SESSIONS

(Papers may be added, deleted, or the order may be revised)

THURSDAY, DEC. 2 (MORNING)

9:30– 9:35 Address of Welcome, by A. F. Childers, Jr.
9:35– 9:40 Introduction, by George S. Buchanan
9:40–10:10 Modern Views about Salt-Dome Mechanics, by Paul Weaver
10:10–10:20 Discussion
10:20–10:30 Intermission
10:30–11:00 Types of Gulf Coast Salt Domes, by Oscar Wilhelm
11:00–11:10 Discussion
11:00–11:20 Intermission
11:20–11:50 Recent Sediments of Mississippi Deltaic Mass, by Harold N. Fisk
11:50–12:00 Discussion

Films of special interest will be shown during technical sessions

(AFTERNOON)

2:30– 3:00 Stratigraphy of Frio Formation in Orange and Jefferson Counties, Texas by Milton F. Reedy, Jr.
3:00– 3:10 Discussion
3:10– 3:20 Intermission
3:20– 3:50 Sedimentary Facies of Upper Cenozoic and Recent in Gulf Coast Geosyncline, by Shepard W. Lowman
3:50– 4:00 Discussion
4:00– 4:10 Intermission
4:10– 4:40 Problems of Deep Drilling in Gulf Coast Area, by Olin G. Bell and co-author
4:40– 4:50 Discussion

(EVENING)

6:00– 8:00 Cocktail party by Schlumberger Well Surveying Corporation, at Houston Club

FRIDAY, DEC. 3 (MORNING)

9:00– 9:30 Salt-Dome Configurations, by Marcus A. Hanna
9:30– 9:40 Discussion
9:40– 9:50 Intermission
9:50–10:20 Tertiary History of Gulf Coast Geosyncline, by Martin M. Sheets
10:20–10:30 Discussion
10:30–10:40 Intermission
10:40–11:10 Possible Effects of Salt Intrusions on Sedimentation at Boling Dome, by William M. Cogen
11:10–11:20 Discussion
11:20–11:30 Intermission
Films of special interest will be shown during technical sessions

(AFTERNOON)

2:30– 3:00 Photogeology in Gulf Coast Exploration, by Charles DeBlieux
3:00– 3:10 Discussion
3:10– 3:20 Intermission
3:20– 3:50 Exploration in Gulf of Mexico with Air-Borne Magnetomotor, by Robert H. Ray
3:50– 4:00 Discussion
4:00– 4:10 Intermission
4:10– 4:40 Oil in Gulf of Mexico, by D. A. McGee and A. T. F. Seale
4:40– 4:50 Discussion
4:50– 5:00 Intermission
5:00– 5:30 Recent Developments in Geophysical Exploration Equipment, by C. H. Carlisle

(EVENING)

8:30–12:00 Semi-formal dance, Crystal Ballroom, Rice Hotel

HOUSTON GEOLOGICAL SOCIETY

EXECUTIVE COMMITTEE

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HERSHAL C. FERGUSON, vice-president
R. R. RIEKE, secretary
MARY L. HOLLAND, treasurer

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DONALD I. GAHAGAN, entertainment and dance
MRS. DONALD I. GAHAGAN, Ladies
J. BRIAN EBY, publicity
FRANK J. GARDNER, registration
PAUL B. LEAVENWORTH, program chairman
ARTHUR S. GALE, JR., program technician and equipment

(This is a copy of the form which has been mailed to members)

APPLICATION FOR HOUSING ACCOMMODATIONS, ST. LOUIS, MO.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS—MARCH 14–17, 1949

For your convenience in making hotel reservations for the coming joint meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, March 14–17, 1949, in St. Louis, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if you request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED *must* BE INCLUDED.

Hotel	*For One Person*	*For Two Persons*		*2-Room Suites*
		Double Bed	*Twin Beds*	*Parlor and Bedroom*
BALTIMORE	2.75–3.50	3.75– 4.50	4.00– 5.00	
CLARIDGE	3.00–4.00	4.00– 6.50	5.00– 6.50	10.00 & Up
*DESOTO	2.75–7.00	4.00– 7.00	6.00–12.00	10.50–12.00
*JEFFERSON	3.50–6.00	5.00– 7.00	7.00– 8.00	14.00–22.00
*LENNOX	3.25–6.00	5.00– 6.50	6.00– 8.00	11.00
*MAJESTIC	2.25–3.50	3.00– 4.00	5.00	
*MARK TWAIN	3.00–3.50	4.50– 5.00	5.00– 5.50	
*MAYFAIR	3.25–7.00	5.00– 8.00	6.00– 8.00	11.00 & Up
MELBOURNE	3.50–6.00	5.50– 6.50	6.00– 8.50	12.00–15.50
SHERATON	3.50–6.00	5.25–10.00	5.50–11.00	8.50–15.00
*STATLER	3.50–6.00	5.25– 8.00	7.25–10.00	16.00–19.00

* Downtown

In the event that the hotel room rate structure is changed prior to the above convention, these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED PRIOR TO February 14, 1949
American Association of Petroleum Geologists
Hotels Reservation Bureau
1420 Syndicate Trust Building
St. Louis 1, Mo.

Please reserve the following accommodations for the: Joint convention of the A.A.P.G., S.E.P.M., and S.E.G., in St. Louis, Missouri, on March 14–17, 1949

Single Room..... Double Bedded Room..... Twin Bedded Room.....
2 Room Suite..... Other Type of Room.....
Rate: From $..... to $.....

First Choice Hotel.....
Second Choice Hotel.....
Third Choice Hotel.....

Arriving at Hotel (date)..... hour .....A.M. .....P.M. .....
Leaving (date)..... hour.....A.M. .....P.M. .....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin bedded room requested. Names and addresses of all persons for whom you are requesting reservations and who will occupy the rooms asked for:

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(Individual Requesting Reservations)
Name.....
Address.....
City and State.....

If the hotels of your choice are unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere providing that all hotel rooms available have not already been taken

JOINT ANNUAL MEETING
JEFFERSON HOTEL, ST. LOUIS, MARCH 14–17, 1949

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
SOCIETY OF EXPLORATION GEOPHYSICISTS

The joint annual meeting of the three petroleum exploratory societies will be held at the Jefferson Hotel, St. Louis, Missouri, on March 14, 15, 16, and 17, 1949.

The official form of "Application for Housing Accommodations" was mailed to each member last July. If any member, particularly anyone who became a member since July, has not received this form, he may obtain a copy, from A.A.P.G. headquarters, Box 979, Tulsa 1, Oklahoma.

All requests for hotel rooms should be made by returning the housing form to the American Association of Petroleum Geologists, Hotels Reservation Bureau, 1420 Syndicate Trust Building, St. Louis 1, Missouri. Requests for reservations should be made as far in advance of February 14, 1949, as possible, and should contain all information requested on the form. Receipt of requests will be acknowledged and filed in order of receipt at the Housing Bureau. Actual assignments will be made in the various hotels and confirmations will be mailed about 60 or 90 days prior to the convention. Members who request reservations, but later find they can not attend, should notify the Hotels Reservation Bureau without delay. Blocks of rooms will not be reserved. All rooms must be reserved in the names of individuals.

Anyone who has not returned the housing request should not postpone it. Officers, authors, and committee members, particularly, are requested to reply promptly.

The executive committees of the societies constitute the committee for arrangements and program. Certain convention chairmen will be named and details will be announced later. As no local group is sponsoring this meeting, special entertainment features of recent annual meetings will be omitted. Entertainment is to be on a pay-as-you-go basis. A reasonable registration fee will be charged. A dinner-dance and a field trip are being planned.

A.A.P.G. TECHNICAL PROGRAM

President Weaver has appointed W. B. WILSON, Gulf Oil Corporation, Tulsa, Oklahoma, to be chairman of the technical program committee for the A.A.P.G. NORMAN S. HINCHEY, Washington University, St. Louis, Missouri, is vice-chairman in charge of technical service.

Members planning to submit papers should send, *in duplicate*, in double-spaced typewritten form, their name, company or professional connection, subject of paper, and a 200-word abstract, to chairman WILSON, by January 1, certainly not later than February 1. Papers will be selected for the program to conform with the planned subject matter acceptable for oral presentation and to conform with the time available. Papers not acceptable for oral delivery may be included in the printed program by title and abstract.

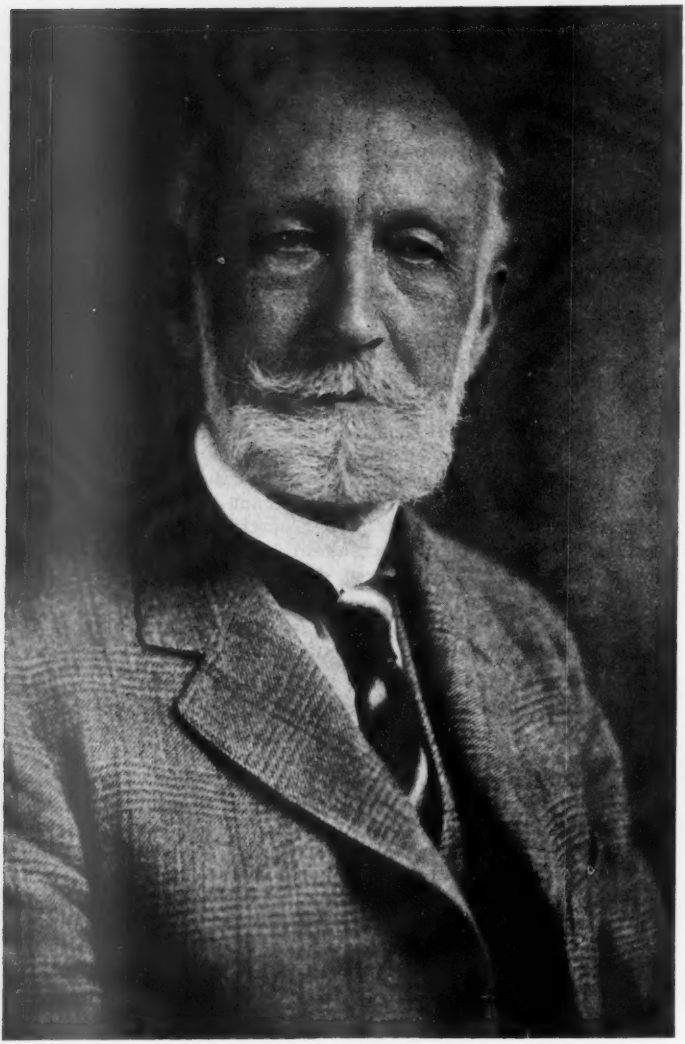
Tentatively, the A.A.P.G. program will include a half day of presidential addresses and awards; a half day of papers of common interest for the joint session; a half day of papers on the theme of "Reefs"; a half day devoted to foreign papers; a half day of oil-field descriptions; and a half day of important miscellaneous papers.

THE EXECUTIVE COMMITTEE

Tulsa, Oklahoma
October 20, 1948

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 11 (NOVEMBER, 1948), PP. 2168-2176, 2 FIGS.

MEMORIAL



ALFRED CHURCH LANE
(1863–1948)

On the morning of April 15, 1948, death came to Alfred Church Lane, one of America's really great scientists and teachers. He died suddenly in New York at the age of 85 as he would have desired—no prolonged illness; his mind and body active to the very end. He was born in Boston, January 29, 1863, a member of the eleventh generation of his family in America.

Dr. Lane prepared for college at the Boston Latin School and was graduated from Harvard in 1883. He studied at Heidelberg from 1885 to 1887, one of his teachers being the famed Dr. Robert Bunson. He received his A.M. and his Ph.D. from Harvard in 1888. It is significant to note that Dr. Lane taught mathematics at Harvard from 1883 to 1885, perhaps explaining, in part, his disciplined approach to the science of geology. He was a scholar who read Latin, Greek, French and German. His intellectual energy was great and his curiosity and interest were unbounded. He was fond of saying, "The larger the area of one's knowledge, the greater the circumference of one's ignorance."

He was married in April, 1896, to Susanne Foster Lauriat, who survives him. His marriage was long and singularly happy, made more so by the birth of three children who also survive. These are Mr. Lauriat Lane of Cambridge, professor Frederic C. Lane of Baltimore and Mrs. C. Dana Rouillard of Toronto.

In 1889 he was appointed petrographer on the Michigan Geological Survey and instructor in the Michigan College of Mines at Houghton. In 1892 he became assistant State geologist and in 1899 State geologist of Michigan. It was during this period that he wrote many of his fundamental and distinguished papers on geology. His classic work was probably the Geology of the Lower Peninsula, followed in 1908 by his Geological Section of Michigan. To these should be added his famed Monograph on the Keweenaw Series. He was the first to study the geology of Isle Royal on Lake Superior and published the first report on the geology of the island. His regional studies in Michigan will continue to be, for years to come, the starting point for new lines of approach to the research on Michigan regional geology and stratigraphy.

His interest in petroleum geology was avid. He pointed out as early as 1908 the structural possibilities of the Michigan sedimentary basin and was the first to recognize the importance of "connate" water, a word he introduced to geological literature in 1899.

In 1909 he became Pearson professor of geology and mineralogy at Tufts College and in 1936 professor emeritus. From 1922 to 1944, Dr. Lane was chairman of the National Research Council committee on the estimation of the age of the earth by atomic disintegration. During this time he originated, promoted, directed, and organized in laboratories the world over, chemical, physical, and geologic research on this problem. He became, therefore, one of America's first scientists to apply mathematical analysis to some of the basic problems of atomic energy. All through the years, beginning in the early twenties and even to the present year, he was engaged in world-wide correspondence with scientists who were doing important work in this field.

His honors have been many. In 1929 he became the first consultant in science ever appointed to the Library of Congress. Beginning in 1924 he was a member of the Board of Visitors of Harvard Observatory. He was chairman of the Division of Geology of the American Association for the Advancement of Science in 1907 and in 1931 he was president of the Geological Society of America and took the annual meeting to Tulsa, Oklahoma, something of an innovation for this distinguished group which heretofore had held its meetings in the East. During the last war when he was past 80, he reactivated his interest in the Boy Scout movement and was awarded the Silver Beaver for his long and unselfish service to all phases of scouting.

Dr. Lane was a member of the Harvard Chapter of Phi Beta Kappa and of Sigma Xi. He was a member of the American Institute of Mining and Metallurgical Engineers, the American Association of Petroleum Geologists, the American Geophysical Union and an honorary member of the Michigan Academy of Science and the Geological Society of

Belgium. He also maintained membership in the Boston Geological Society, the Michigan Engineering Society, the American Association of Scientific Workers, the American Association of University Professors, the Cosmos Club of Washington and numerous others.

On three different occasions he was an official delegate from America to the International Geological Conferences. During the first World War he was with the overseas Y.M.C.A. and in 1919 head of the department of mining, A.E.F., Université de Beaune in France. He was a special lecturer in economic geology at the Field Museum of Natural History, the University of Michigan and the University of Wisconsin. He received an Sc.D. from Tufts in 1913 and in 1940 was awarded its Ballou Medal for distinguished service to education and to the Nation.

Dr. Lane was a prolific writer, having published the astonishing number of 1,087 articles, mainly on geology, religion, politics, public affairs, and economics. He was active in many fields of geology including stratigraphy, mineralogy (one of the pleochroic minerals, laneite, was named for him), geochemistry, petrology, geomorphology, geophysics, petroleum, economic, igneous and ground-water geology. He had a keen interest in climatic variations particularly of the northern latitudes and would discuss "permafrost" at the drop of a hat. His papers in these various fields numbered 234. Many of these were short but 5 exceed 275 pages in length and one totaled 983 pages.

The annual meetings of the Geological Society of America were always attended by Dr. Lane where he was usually chairman of one or more of the section meetings, always taking a leading part in the lively discussions which followed the delivery of the papers. He was a familiar and beloved figure; everyone knew him or knew who he was. His name was starred in all issues of *American Men of Science* beginning with the first issue in 1903, placing him among the leading scientists of the world.

Dr. Lane was a man of ideas—he was a man of many places. One day he would be considering what happens to international boundaries beyond the three mile limit, a problem of importance to those who search for oil on the continental shelf. Next it would be universal military training, preparedness, international relations, geothermal gradients, or displaced European geologists that claimed his attention. He used to say at the year's end, that he always had a lot of ideas which he would sell cheap. His office was a wonder to behold and it is reported to have held more reprints per cubic foot than any other office in Christendom.

In his teachings as in his life he was at all times ready to participate in the solution of the problems facing society. He had a fine sense of humor, he was witty, friendly and was always willing to help anyone. There was never the slightest trace of envy or jealousy and he was never known to criticize harshly anybody. He was deeply religious, an active, loyal and informed member of the Congregational Church. Grace was always said at his table.

We can never forget the twinkle in his eye, the warm friendship of his handclasp, the clear mind and perpetually youthful interest in daily occurring events. Those of us who were so fortunate as to know this truly great man can not fail to be better people.

P. E. FITZGERALD

Tulsa, Oklahoma
September 25, 1948

GAYLE SCOTT

(1894–1948)

Gayle Scott, eminent paleontologist and professor of geology at Texas Christian University, died at his home, 2916 Princeton Street, Fort Worth, Texas, on the morning of May 2, 1948. Eight months of progressively increased suffering occasioned by a brain tumor and two major surgeries preceded the merciful release. He is survived by his wife,

GAYLE SCOTT

the former Mary Elizabeth Waits, whom he married in 1927, and his mother, Mrs. G. M. Scott. A daughter, Mary Gayle, died in 1936 at the age of six years.

Only child of George Moses Scott (1868–1939) and Elzorah Jennings Scott (1873–), Gayle was born October 1, 1894, in Lamkin, Comanche County, Texas. His boyhood was spent on farms near his birthplace and later, Comanche, where his mother now lives.

The many brilliant reflections of Doctor Scott's career are from three facets: his family, his vocation as a faculty member, and his avocation as a research geologist. Trained early in Christian precepts, he came to Texas Christian University as a student through the impressions on his parents of Randolph Clark, minister and co-founder of Add-Ran College which later developed into Texas Christian University. In the university, he was influenced by congenial association with his father-in-law, Edward McShane Waits,

president from 1916 to 1941 and now president emeritus. Devoid of any of the hypocrisy sometimes associated with institutions of religious affiliations, this family—Gayle Scott, his wife and his father-in-law—was ever at ease with religion. It was a vital though unobtrusive component of Dr. Scott's life—something seen and felt rather than heard.

He entered college in 1913 and received his Bachelor of Arts *in absentia* in June, 1917. As a member of the senior class which enlisted as a unit in the armed forces in April, 1917, he trained at the 1st Officers Training Camp, Leon Springs, Bexar County, Texas, and received his commission as a second lieutenant in August, 1917. Overseas to France in September with a group of unattached officers, he attended the French artillery school at Saumur and in November was ordered to the 101st Field Artillery in training at Coetquidan and assigned to Battery E. He served with distinction, passed unscathed through the major offensives of Apremont, the Aisne-Marne, St. Mihiel, and the Meuse-Argonne, and was decorated with the Silver Star with two oak leaves and the Order of the Crown of Belgium. The Silver Star and Order of the Crown were awarded for action at La Sacerie Fme., about 4,000 meters north of Château-Thierry. According to an account[1]

'. . . part of our forces were trapped (22 July, 1918) in a wooded sector, from which there was no escape except through heavy German artillery and machine gun fire.' Scott recalls.

'We managed, however, to lay down a covering barrage of our own and I moved a part of our men into another wood, somewhat removed and more shielded than the first. These men then laid down another fire cover while the remainder of the men were moved out of the trap.'

The two oak leaf clusters, as recalled by Scotty's commanding officer,[2] were awarded

For marked gallantry on 2 June, 1918 in front of Noviant when Lt. Gayle Scott prevented serious loss of life by removing ammunition from beneath burning camouflage at Battery E gun position.

and

For marked gallantry and meritorious service in the capture of Torcy, Belleau, Givry Bouresches Woods, Rochet Woods, Hill 190 overlooking Château-Thierry, Etrépilly, Bézuet, Epieds, Trugny and La Fère Woods to the Jaulgonne-Fère-en Tardenois Road during the advance of this Division against the enemy from July 18th to 25th, 1918, in the 2nd Battle of the Marne.

A token measure of the esteem in which he was held by his battery-mates is expressed by a bronze statuette presented him by the mayor of Salem, Massachusetts, at a dinner preceding the 3 January, 1947, reunion of the Dugout Club, a select group of veteran officers of the 51st Artillery Brigade of the 26th Division.

Prior to the country's entry into the recent war he attempted to get into combat in Greece. After the declaration of war, and until his applications were rejected for physical reasons, he offered his services for military intelligence in North Africa where his knowledge of the French language and customs could have been immediately applied. It was characteristic of Scotty that upon rejection for overseas duty he voluntarily served as military drill instructor of the University's Army-Navy pilot training program in the summer of 1942.

As a member of the department of biology and geology of Texas Christian University from 1913 till his death, he served the school as a student (1913–1917, 1919–1920), instructor (1919–1921), assistant and associate professor (1921–1925), and professor (1925–1948), a span of 35 years interrupted only by his war years and a sabbatical leave in 1925 for advanced graduate study in France. With a secure background in geology and biology received under the tutelage of Will McLain Winton, inspiring educator and head of the department since 1913, Scott received his Master of Arts in 1920. The second Master's

[1] *Texas Christian University Skiff*, Vol. 41, No. 27 (April 30, 1943).

[2] Thomas Sanders, formerly Captain, Battery E, 101st F.A., personal communication, August 18, 1948.

candidate in geology trained by Winton, he and Winton from 1925 to 1948 approved for the master's degree in geology at T.C.U. a total of 30 candidates. Seven of this group and two others with bachelor's training under their guidance pursued higher graduate study and completed doctorate requirements at Johns Hopkins (2), Kansas (1), Michigan (1), Princeton (3), Stanford (1), and Texas (1). This is a record rarely approached by institutions of greater resources than T.C.U.; and it bears eloquent witness to the quality of instruction and inspiration furnished by the team of Winton and Scott.

Scott's stratigraphic research on the Mesozoic and particularly the Cretaceous of Texas was instigated by week-end collecting trips as a student under Winton. His master's thesis, "The Duck Creek Formation of North Texas," initiated an investigation of pyritic micromorphs, especially ammonites, which continued throughout his life.[3] The most modest and unassuming of men, he was nevertheless fearless in expressing his considered judgment. As he was never hesitant to disagree with dogmatism or speculation by the pundits of his time, his doctoral dissertation possibly drew more castigation than any since written concerning Texas geology. In the dissertation, which was prepared under the direction of W. Kilian and Léon Moret, published in the *Annales*, Université de Grenoble, and entitled "Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas," Scott presented the idea of regressive deposition of the Woodbine sand and suggested the correlation of the Midway of Texas with the Danian of Europe. Criticism on the latter point was sufficiently vitriolic to induce him from then on to gather additional data on the Midway and Danian. Nine years later, his results were published under the title "Age of the Midway Group."[4] The excellence of this paper is perhaps best attested by the meager citations of this work by Scott's original antagonists and the absence of convincing rebuttals to his conclusions by later opponents. In 1940, six years later, his continuing research on this point was summarized and presented before the Paleontological Society in Philadelphia.[5] Had Doctor Scott's health permitted, he would have enthusiastically examined a recent study by Brotzen on the Swedish Paleocene. The former's correlation of the Texas Midway is partially confirmed by Brotzen who correlated the lower Midway (Kincaid) as upper Danian, the upper Midway (Wills Point) as Seelandian Paleocene.[6]

The appended list of titles indicates the scope of Scott's geologic research. Monographic studies are those on Trinity Cretaceous cephalopods[7] and Upper Paleozoic ammonites in Texas,[8] the latter co-authored with the late Frederick Byron Plummer. Doctors Scott and Plummer independently and in collaboration collected material for a decade prior to publication of this summary, meanwhile reporting on progress by way of presentations before various societies. The death of Dr. Plummer in 1947 interrupted the completion of a continuing joint project on the ammonoid fauna of the Millsap Lake (Strawn Pennsylvanian) formation of Texas. In addition to the studies on the Paleozoic and Cretaceous Mesozoic of the southwestern United States, reference may be made to an Ethiopian Jurassic cephalopod investigation. Though less familiar with the taxonomic literature of this period

[3] A manuscript on "Pyrite Faunas of the Washita and Eagle Ford Groups of Texas Cretaceous and the Paleoecological Significance," abstracted in the *Bulletin* of the Geological Society of America, December, 1940, will be submitted for publication at an early date. FEL

[4] *Bull. Geol. Soc. America*, Vol. 45, No. 6 (1934).

[5] "Cretaceous-Tertiary Relationships in the Coastal Plain Area of Texas" (abstract), *Bull. Geol. Soc. America*, Vol. 51, No. 12, Pt. 2 (December, 1940), p. 2006.

[6] *Sver. Geol. Under Årsbok 42* (1948), No. 2, Ser. C. No. 493, pp. 1–140; 19 pls., 3 tables, 41 text figs.

[7] *Univ. Texas Pub. 3945* (1940).

[8] *Univ. Texas Bull. 3701* (1937).

and hindered by the imperfect preservation and the obstructing matrix of the fossils sent him, he nevertheless accepted the invitation of the American Museum of Natural History to prepare the fourth part of "Palaeontology of Harrar Province, Ethiopia." His enthusiasm in observing the relationships to faunas with which he was more familiar resulted in his usual creditable completion of the investigation.

Most closely associated with the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Paleontological Society of America, Scott was also professionally affiliated with the Société Géologique de France, Geological Society of America, Fort Worth Geological Society, American Association for the Advancement of Science, North Texas Biological Society, Texas Academy of Science, and American Geophysical Union. He was an active participant in the affairs of these organizations, and his officerships and committee memberships brought much credit to him and to Texas Christian University. He was twice vice-president of the Paleontological Society (1934 and 1938), president of the S.E.P.M. in 1939, and secretary-treasurer of the latter society from 1930 to 1937. From 1933 to 1938 the *Journal of Paleontology* and *Journal of Sedimentary Petrology* were distributed from the laboratory of the University. This task, in addition to secretarial duties, resulted in a world-wide acquaintance with the geologic fraternity. As the retiring president, his address on "Paleoecological Factors Controlling the Distribution and Mode of Life of Cretaceous Ammonoids in the Texas Area" was delivered at the 14th annual meeting of the S.E.P.M. in Chicago despite an unfortunate automobile accident a few hours out of Fort Worth which ruined his illustrative slides, necessitated a rapid re-preparation and complete change in travel plans. The recognition given this paper was indicated by the unprecedented honor of dual publication in the July, 1940, issues of the *Journal of Paleontology* and the *Bulletin* of the A.A.P.G.

As a member of the American Association of Petroleum Geologists since 1921, he served on the following committees:

Business Committee: 1934–36, 1939, 1944–47
Research Committee: 1939–40
Committee on Applications of Geology: 1943
Geologic Names and Correlation Committee: 1946–47
Sub-committee on Mesozoic: 1943–45
Advisory and Special Projects Sub-Committee: 1946–47

In 1944 he was elected editor of the *Bulletin*, a post which he filled with distinction for three years. It was work that he found especially congenial, and he discharged his editorial duties with enthusiasm and enjoyment. Honored by selection as one of the Association's thirteen Distinguished Lecturers of 1944, he preceded his formal address on "Stratigraphic Correlations and Depositional Environments Indicated by Ammonoid Occurrences in the Texas Pennsylvanian" with his editorial plans. That the quality of papers published during the war-years of his editorship was maintained at a high standard is scant recognition of the hours he spent editing each manuscript submitted.

Dr. Scott's reluctant resignation as editor came about with his election in 1947 as president of the Southwest Conference and realization that his work as president was so heavy that he could not do both. As chairman of the faculty committee on athletics and representative of T.C.U. to the Southwest Conference during the period 1937–1948, he rendered an invaluable service to the University and to the cause of athletics in the southwest. At the time of his death he was serving his second year as president of the conference. An editorial by Walter Humphrey in the *Fort Worth Press* of May 4, 1948, gratefully acknowledged his untiring efforts in this work—"He composed many a difference, smoothed many a controversy, lived a good life and a useful life in the service of his fellow man."

Confronted with far more than his share of physical and emotional blows, Scotty absorbed all with his balanced humor and fine philosophy of life. Kindly, tolerant, but with unshakable integrity, he was the highest type of Christian gentleman . . . a man of "high thoughts and amiable words, and courtliness and a desire for fame, and all that makes a man." It was, perhaps, his greatest gift to see life steadily and see it whole. This sense of perspective—gained, I think, more by study than by nature—was the result of an imaginative mind disciplined by science. Life and living viewed through eyes accustomed to looking down the vistas of geological eras, may be seen in better proportion and perspective; and those of us who caught that vision in his classroom are forever in his debt.

Because he was taken in the prime of his life, it is often difficult to become reconciled to his absence. A beloved son, husband and father, a gallant soldier, a dedicated and accomplished teacher, and a famed scientist, he became a part of all those with whom he came in contact. *Au revoir, hasta la vista, auf wiedersehen,* till we meet again, Scotty!

FRANK EDGAR LOZO, JR.

Houston, Texas
September, 1948

Acknowledgments.—Source materials utilized in preparation of the foregoing have been Colby D. Hall's *History of Texas Christian University,* Texas Christian University Press (Fort Worth, 1947), Russell G. Carter's *The 101st Field Artillery,* Houghton Mifflin Company (Boston, 1940), and the files of the *Fort Worth Press, Forth Worth Star-Telegram,* and *Texas Christian University Skiff.* Individuals who have materially contributed are Willis G. Hewatt, Professor W. M. Winton, Thomas Sanders, and W. S. Adkins. Mrs. Gayle Scott has diligently and devotedly assisted in every manner and to her the writer is especially grateful.

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AT HOME AND ABROAD

NEWS OF THE PROFESSION

F. R. S. HENSON, formerly senior subsurface geologist of the Iraq Petroleum and associated companies, has been transferred to London headquarters of the same organization, as research geologist in charge of the new geological Research Center. Henson graduated at the Royal School of Mines, London, in 1924, did field and subsurface geology with the North Venezuelan Petroleum Company in Venezuela until the end of 1926, and spent the remaining 21 years in the Middle East. He has toured oil fields in Europe and the U. S. A. and expects to pay frequent visits to the Middle East where he has technical supervision of divisional and field laboratories.

FRANK J. GARDNER, of the Rinehart Oil News Company, has been transferred from its Houston regional office to the general office in Dallas, Texas. Gardner has been associated with this organization since 1940 in the capacity of chief geologist. During this time he has written many featured books released by the company, including "North Texas Oil," "South Texas Oil," and "Texas Gulf Coast Oil." In the Dallas office, he will act as general manager of the newly created Central Information Office. His duties will include public relations, promotion, and supervision of all books and special publications. His address is Box 1208, Dallas, Texas.

JAMES G. WHITE resigned from the Humble Oil and Refining Company the latter part of August, to accept the position of general manager of the Presidio Company. His new address is 1530 Commerce Building, Houston, Texas.

HENRY L. BOND has been transferred from the Phillips Oil Company, Barcelona, Venezuela, to the Shreveport, Louisiana, geological department of Phillips Petroleum Company, after a 3-year foreign assignment in both Colombia and Venezuela.

JAMES F. SWAIN, partner in the firm of Huntley and Huntley, Pittsburgh, Pennsylvania, died in the crash of a private plane near Kentuck, West Virginia, October 4. Swain was 44 years of age. He was flying from Charleston, West Virginia, to deliver his paper on the program of the Pittsburgh regional meeting of the Association.

ROY E. COLLOM, of Los Angeles, California, died on September 24, at the age of 66 years. Collom joined the A.A.P.G. in 1919. He was recently with the Kettleman North Dome Association, Los Angeles.

THOMAS R. BANKS, independent geologist and operator of San Antonio, Texas, died on September 22, 1948, at the age of 48 years. Previous to his independent work, Banks was employed for several oil companies, most recently as chief geologist in Texas for the Transwestern Oil Company.

MANUEL N. MAYUGA has accepted the position of principal geologist in the Petroleum Division of the Long Beach Harbor Department, Long Beach, California. He was previously with the Long Beach Oil Development Company.

G. FREDERICK SHEPHERD has discontinued his consulting practice in New Orleans, Louisiana, and is now associated with the General American Oil Company of Texas, as chief geologist. His address is Republic Bank Building, Dallas, Texas.

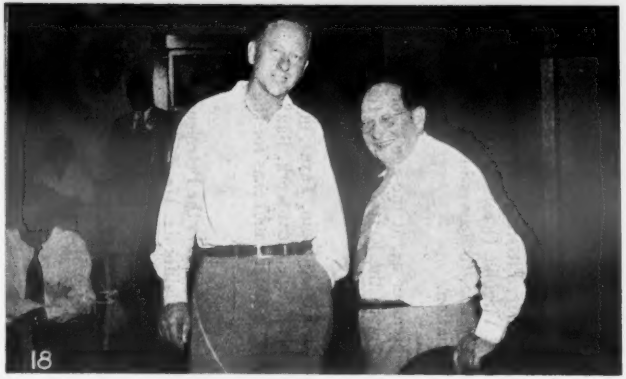

FIG. 1.—Left-to-right. Jed B. Maebius, editor of guidebook, and Paul Weaver, president of A.A.P.G.

FIG. 2.—Left-to-right. Taken at final Stop of Conference. Red-shirt guides. H. E. Summerford, secretary-treasurer, Wyoming Geological Association; P. W. Reinhart, chairman of field conference committee; Robt. Mumford; J. B. Maebius, guidebook editor; P. W. Netterstrom, road-log editor; F. H. Brady, chairman conference arrangements and caravan; J. F. Partridge, Jr.; M. W. Wolf; James F. Fouts.

FIG. 3.—Left-to-right. J. C. McCulloch, committee on arrangements at Lander, and trip leader; J. B. Maebius.

FIG. 4.—Left-to-right. Taken at Lander, informal discussion following evening lecture by Levorsen. F. A. Morgan, Jr., J. R. Fanshawe, A. I. Levorsen, R.T. Littleton, S. H. Knight.

H. H. BRADFIELD, senior geologist with The Texas Company at Fort Worth, has been appointed senior geologist for the company in the North Texas division at Wichita Falls, Texas, succeeding W. D. Kelly who resigned to enter the consulting field.

The Fourth Empire Mining and Metallurgical Congress is to be opened in London, July 9, 1949. Information may be obtained from Joint General Secretaries, Fourth Empire Mining and Metallurgical Congress, 436 Salisbury House, Finsbury Circus, London, E. C. 2.

The Pacific Section of the Association held meetings at the University of California, Berkeley, October 4, at the El Tejon Hotel, Bakersfield, October 5, and at the Clark Hotel, Los Angeles, California, October 6, to hear GERALD FITZGERALD, chief of the Topographic Branch of the United States Geological Survey speak on "Modern Mapping Methods." Fitzgerald, one of the A.A.P.G. Distinguished Lecturers, organized and assisted in the original development of Trimetrogon aerial photographic mapping, and is the recipient of the Fairchild Photogrammetric Award of 1944.

W. T. MENDELL has resigned as area exploitation engineer for the Shell Oil Company, Houston, and has opened offices in the Second National Bank Building, Houston, Texas, as a consultant petroleum geologist and engineer.

THOMAS CLEMENTS, head of the department of geology of the University of Southern California, announces the appointment of ORVILLE L. BANDY and RICHARD H. MERRIAM as assistant professors of geology to teach micropaleontology and physical and optical mineralogy, respectively.

FIG. 4.—Left-to-right. Taken at Lander, informal discussion following evening lecture by Levorsen. F. A. Morgan, Jr., J. R. Fanshawe, A. I. Levorsen, R.T. Littleton, S. H. Knight.

FIG. 3.—Left-to-right: J. C. McCulloch, committee on arrangements at Lander, and trip leader; J. B. Maebius.

The Society of Vertebrate Paleontology held its annual field conference in August in northeastern Wyoming. The guide-book for this conference will doubtless be of interest to many petroleum geologists. The table of contents follows.

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Generalized Section for Northeastern Wyoming 2
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The guide-book is available for one dollar ($1.00); orders should be addressed to Paul O. McGrew, Department of Geology, University of Wyoming, Laramie, Wyoming.

JAMES G. JOHNSTONE is an instructor in chemical and metallurgical engineering at Purdue University, Lafayette, Indiana.

R. M. STAINFORTH is on the paleontological staff of the International Petroleum Company, Ltd., Negritos, Peru.

PIERRE BUTTICAZ may be addressed at 2, Boulevard des Philosophes, Geneva, Switzerland.

DWIGHT E. WARD has this address: c/o N. V. S. V. P. M., Soengi Gerong, Palembang, Sumatra, Netherlands East Indies.

The executive committee of the Association met at Pittsburgh, Pennsylvania, October 3, the day before the technical sessions of the Association regional meeting which was arranged by the Pittsburgh Geological Society. Officers present were president PAUL WEAVER, secretary-treasurer J. V. HOWELL, and editor CLARENCE L. MOODY.

President PAUL WEAVER is continuing his official visits to local groups of members throughout the United States. Also, together with secretary-treasurer J. V. HOWELL, he met with the Alberta Society of Petroleum Geologists in Calgary, in August, and he appeared on the program of the South Texas Section meeting in Mexico City, in October, at which time he spoke on "Variations in the History of Continental Shelves." On October 29, president Weaver spoke at the annual fall meeting of the Pacific Section, in Pasadena, on the subject, "History of the Continental Shelf of the Gulf of Mexico."

SAMUEL P. ELLISON, JR., formerly with the Stanolind Oil and Gas Company at Wichita Falls, Texas, has joined the geological department of the University of Texas at Austin.

G. R. PRICE has transferred from the Tropical Oil Company at Bogota, Colombia, to the Creole Petroleum Corporation at Caracas, Venezuela.

MAX W. BALL, director, United States Department of the Interior Oil and Gas Division, Washington, D. C., addressed the University of New Hampshire, Durham, New Hampshire, October 8, in connection with the installation of president A. S. Adams. His subject was "Mineral Resources and Human Resourcefulness."

HUBERT G. SCHENCK has an article in *Science*, Vol. 108, No. 2806, pp. 367–72, entitled "Natural Resources Problems in Japan."

PARKE D. SNAVELY, JR., has set up an office for the Fuels Section of the United States Geological Survey in Portland, Oregon. He will be engaged in work on southwestern Washington coal this winter.

W. B. WILSON, consulting geologist of the Gulf Oil Corporation and A. RODGER DENISON, chief geologist of the Amerada Petroleum Corporation, talked at the Tulsa Geological Society meeting, November 1, on their observations and experiences in connection with their visit as delegates of the A.A.P.G. to the 18th International Geological Congress, in London in August and September.

MILTON FRANK REEDY, JR., chief geologist, Crown Central Petroleum Corporation, spoke on "The Stratigraphy of the Frio Formation of Orange and Jefferson Counties, Texas," at the October 25 meeting of the Houston Geological Society.

L. MURRAY NEUMANN has opened an office at 412 Palace Building, Tulsa, Oklahoma. He has retired from active service with the Carter Oil Company.

J. L. MUIR has been appointed chief geologist of the Champlin Refining Company, Enid, Oklahoma, succeeding R. L. CLIFTON, who retires after many years with Champlin. Muir served 15 years with the Amerada Petroleum Corporation.

SHERWOOD BUCKSTAFF has been appointed manager of exploration of the Houston area for the Shell Oil Company, Inc. LEO R. NEWFARMER has been transferred to the Pacific Coast as exploration manager with headquarters in Los Angeles.

CHARLES P. BERKEY, Newberry professor emeritus of geology at Columbia University, has been awarded the Kemp Medal "for distinguished service in geology." The award was made by Dwight D. Eisenhower, president of Columbia. Berkey is the first

recipient of the award which was established last year in honor of the late James Furman Kemp, founder of the geology department and a pioneer in the field of engineering geology. Executives of 19 of the major extractive industries were among those present.

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 2149)

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By

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Tulsa, Oklahoma, and Stanford University, California

I. General Material:—National and continental in area
- A. Publications and non-commercial publishing agencies, regional, national, and continental
- B. Bibliographies, general
- C. Dictionaries, glossaries, encyclopedias, statistics, handbooks
- D. Miscellaneous books and publications of general geological interest
- E. Commercial map publishers
- F. Regional and national geologic and physiographic maps
- G. State and Province geological maps
- H. Trade journals: oil, gas, mineral industry
- I. Libraries furnishing photostat and microfilm service
- J. Thin-section and rock-polishing service

II. Specific Material:—State and Province in area
- A. Canada, by provinces, and Newfoundland
- B. Central American countries
- C. Mexico
- D. United States—states and territories

Originally published as Part II of the August, 1946, Bulletin

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Los Angeles 12, California

Monthly meetings. Visiting geologists are welcome.

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Standard Oil Company of California, Box 1200

Dinner meetings on 2d Tuesday of each month or as announced, El Tejon Hotel, Bakersfield.

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136 New Customhouse
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410 Boston Building

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

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Humble Oil and Refining Company,
Box 506

Meetings will be announced. Visiting geologists and friends are welcome.

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Meetings will be announced.

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Sun Oil Company, Box 717

Vice-President - - - - - - - Maynard Rogers
Independent, 417 Court Building

Secretary-Treasurer - - - - - - D. G. Sutton
Sun Oil Company, Box 717

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

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Independent, 703 Union Nat'l Bank Bldg.
Vice-President - - - - - - - Don W. Payne
Sinclair Prairie Oil Company
Secretary-Treasurer - - - Shirley E. Lenderman
Stanolind Oil and Gas Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

LOUISIANA

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NEW ORLEANS, LOUISIANA

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Vice-President and Program Chairman - - - - - - - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Secretary-Treasurer - - - - - - Ame Vennema
Schlumberger Well Surveying Corporation

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Barnsdall Oil Company
427 Ricou-Brewster Building
Vice-President - - - - - Walter F. Hamilton
Gulf Refining Company
Box 1731
Secretary-Treasurer - - - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

LOUISIANA

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Amerada Petroleum Corporation
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Magnolia Petroleum Company, Box 872
Treasurer - - - - - - - - - Philip R. Allin
Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

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Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
Business Manager - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

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Vice-President - - - - - - - Carl F. Grubb
Superior Oil Company
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Consultant, Box 2571, West Jackson

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

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Westheimer-Neustadt Oil Company, Box 974
Vice-President - - - - - - Richard G. Kendall
The California Company, Box 153
Secretary-Treasurer - - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - Robert R. Wheeler
Consultant, 1216 Petroleum Building
Vice-President - - - - - - - L. R. Wilson
Carter Oil Company
1300 Apco Tower
Secretary - - - - - - - - - - John Janovy
Tide Water Associated Oil Company
918 Hales Building
Treasurer - - - - - - - - - Elwyn R. Owens
Phillips Petroleum Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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The Texas Company
Box 1007, Shawnee
Secretary-Treasurer - - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

OKLAHOMA

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TULSA, OKLAHOMA

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Consultant, Box 2204
2d Vice-President - - - - - Thomas E. Matson
Pure Oil Company
Secretary-Treasurer - - - - - - - Noel Evans
Consultant, 1510 Philtower Building
Editor - - - - - - - - - - John C. Maher
U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Lorton Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

PENNSYLVANIA

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Box 2038
Secretary - - - - - - - - - James C. Patton
Equitable Gas Company
610 Wood St.
Treasurer - - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

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President - - - - - - - Frank B. Conselman
Consulting Geologist
Vice-President - - - - - - - - J. R. Day
Pan American Production Company
Secretary-Treasurer - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

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CORPUS CHRISTI, TEXAS

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Humble Oil and Refining Company, Box 1271
Vice-President - - - - - - Norman D. Thomas
Pure Oil Company
Secretary-Treasurer - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

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Seaboard Oil Company
1400 Continental Building
Vice-President - - - - - - - John T. Rouse
Magnolia Petroleum Company
P.O. Box 900
Secretary-Treasurer - - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
Executive Committee - - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
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Atlantic Refining Company
205 Manziel Building
Vice-President - - - - - - - - J. C. Price
Magnolia Petroleum Company
Box 780
Secretary-Treasurer - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

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The Texas Company
Box 1720
Vice-President - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Secretary-Treasurer - - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

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Gulf Oil Corporation, Box 2100
Vice-President - - - - - - Hershal C. Ferguson
Consultant, 935 Esperson Building
Secretary - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
Treasurer - - - - - - - - Mary L. Holland
Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

TEXAS

NORTH TEXAS GEOLOGICAL SOCIETY
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Independent Geologist, 907 Staley Building

Vice-President - - - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010

Secretary-Treasurer - - - - Ralph H. McKinley
Panhandle Producing and Refining Company, Box 1191

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Cities Service Oil Company, Box 350

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Stanolind Oil and Gas Company, Box 2089

Secretary-Treasurer - - - - - Fred S. Alexander
Standard Oil Company of Texas, Box 2087

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Vice-President - - - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY
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Argo Oil Corp., Box 1814

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Union Oil Company of California

Secretary - - - - - - - - - Cylde W. Turner
Republic Natural Gas Company, Box 1644

Treasurer - - - - - - - - - Jane M. Johnson
Independent, Kerr-McGee Building

Meetings will be announced.

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Editor - - - - - - - - - - W. T. Ziebold
Thomas Circle Road, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P.O. Box 545

President - - - - - - - - - - Henry C. Rea
Consultant, Box 294

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General Petroleum Corporation
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2d Vice-President (Programs) - - W. S. Knouse
Tide Water Assoc. Oil Company, Box 1708

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Chemical Laboratories, Inc., Box 279

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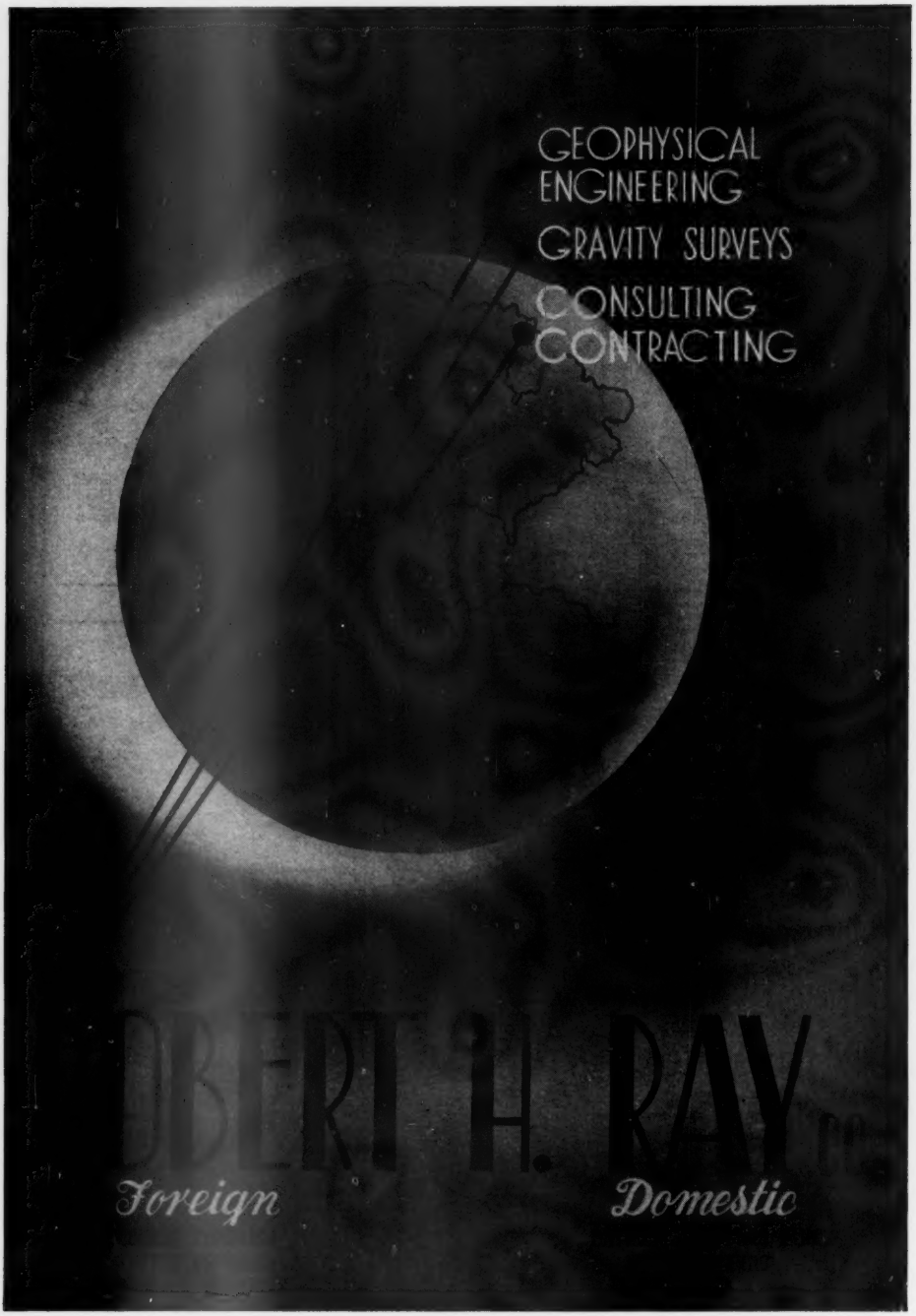
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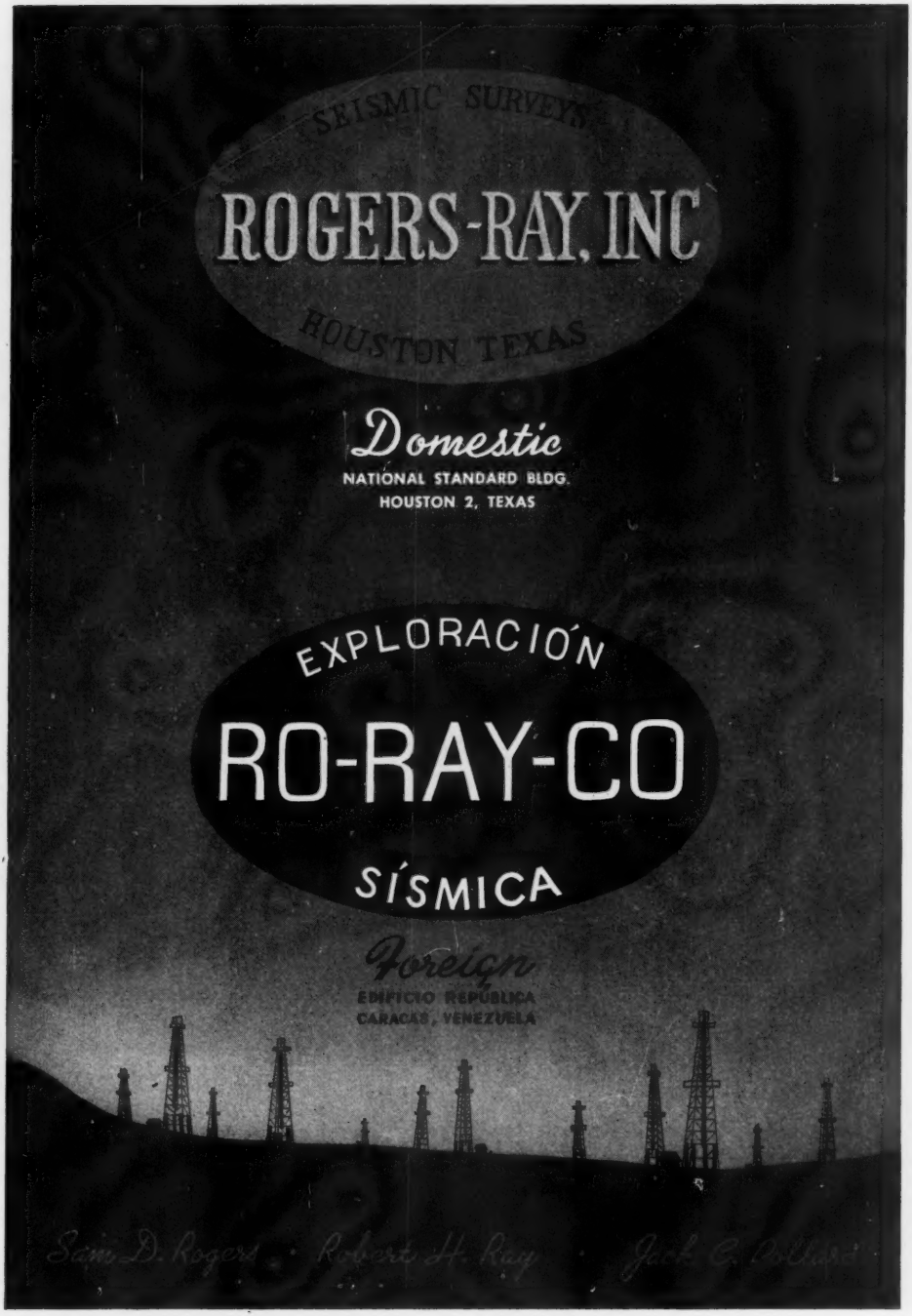
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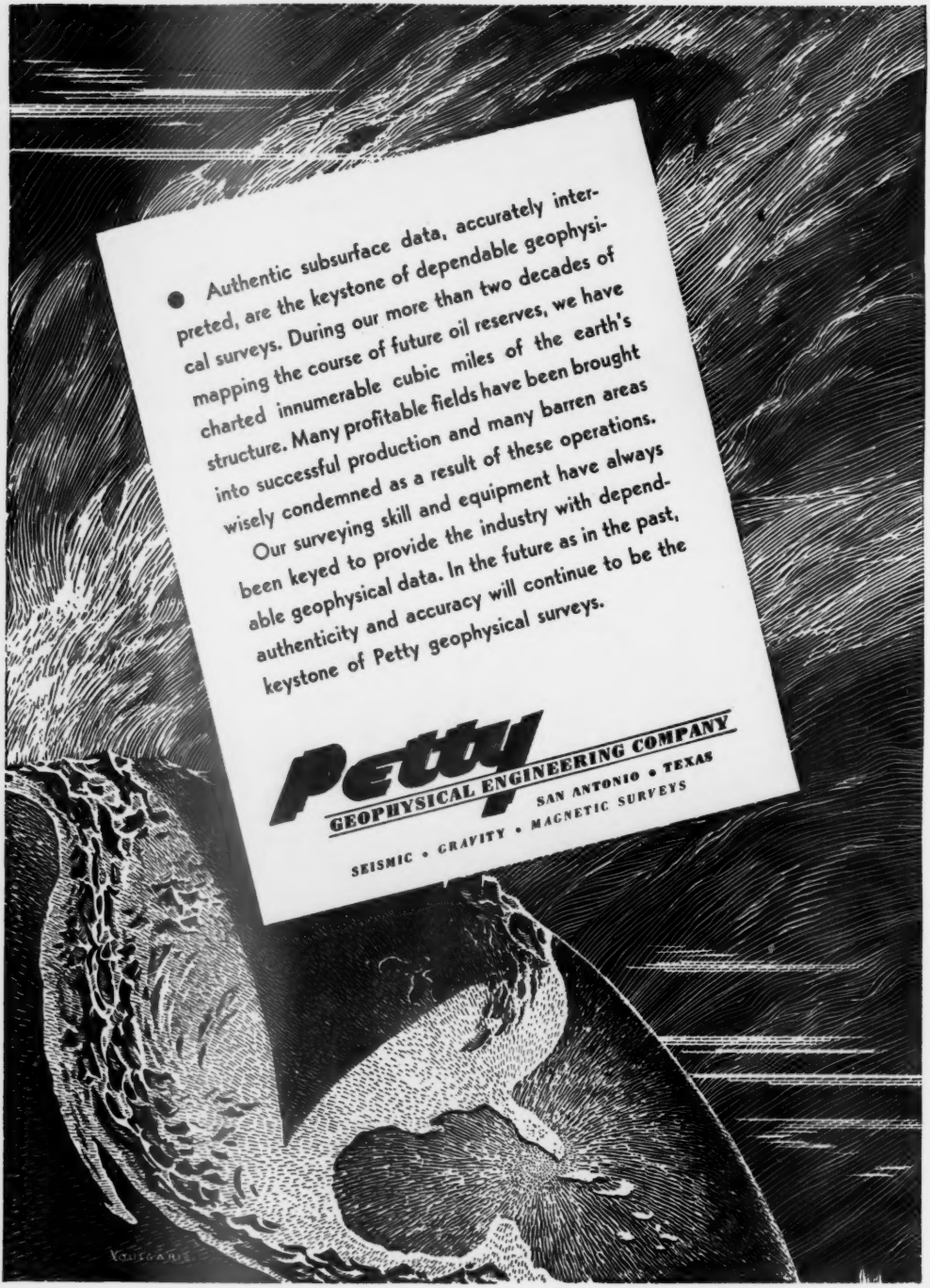
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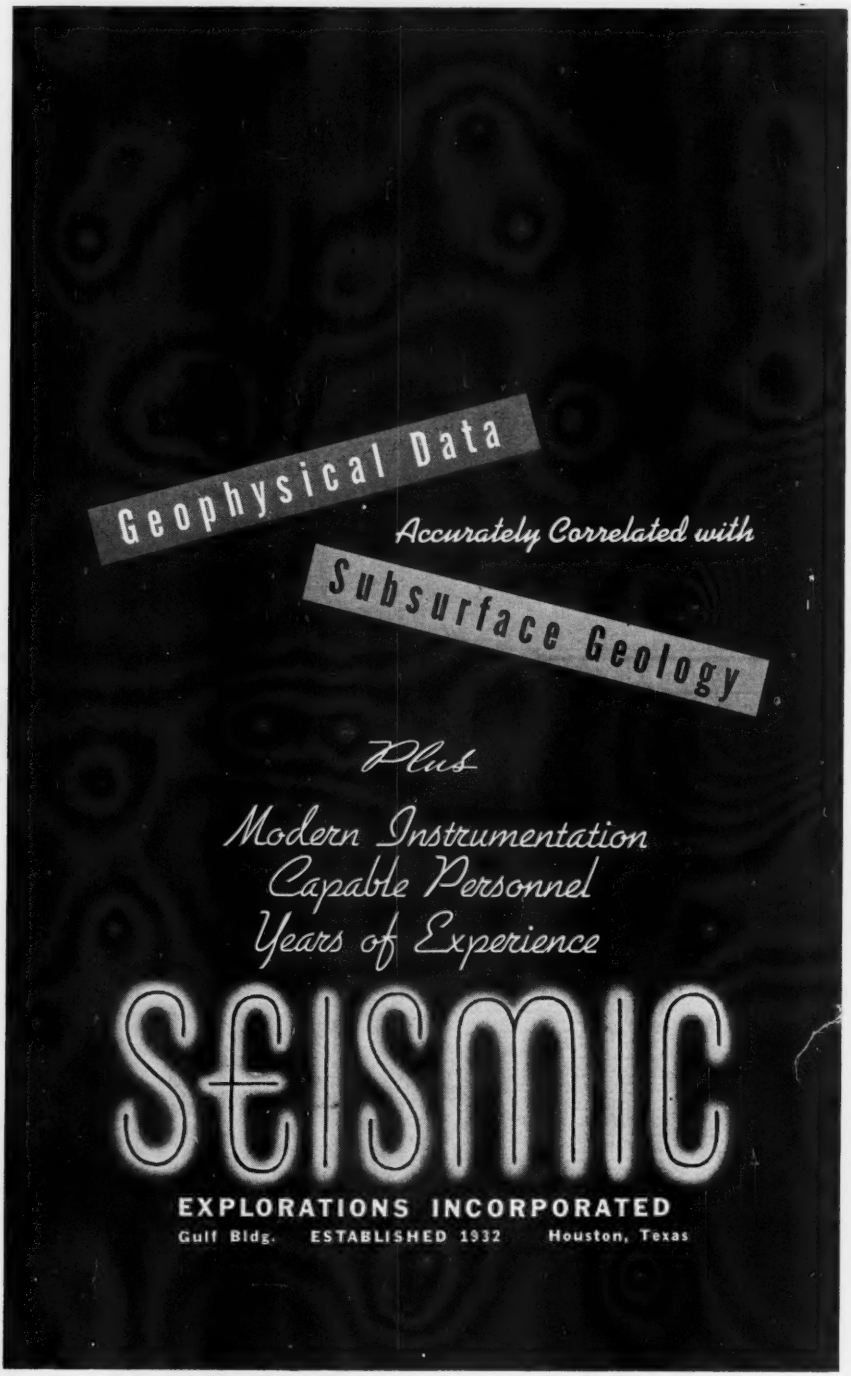
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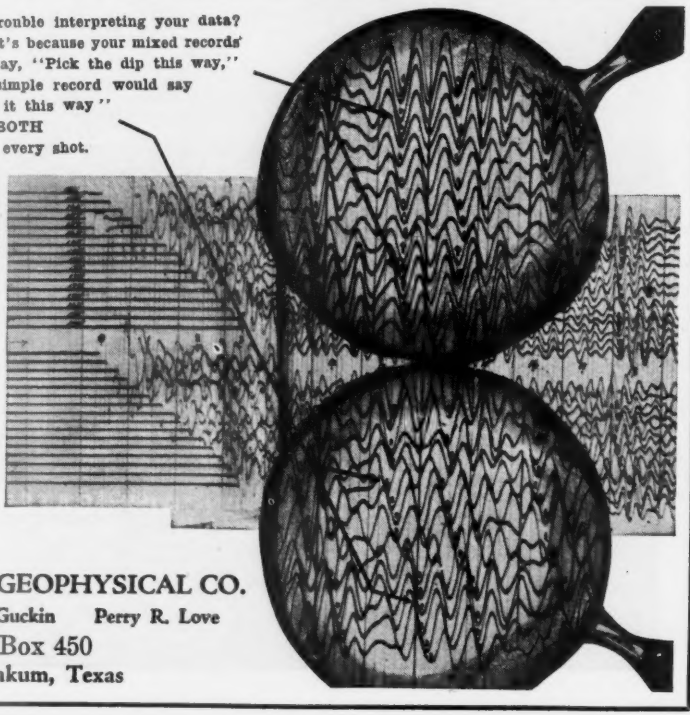

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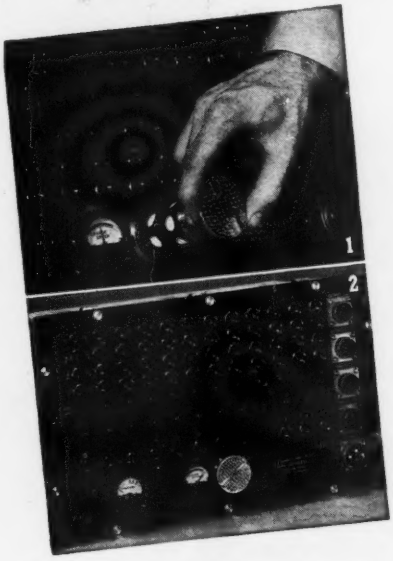

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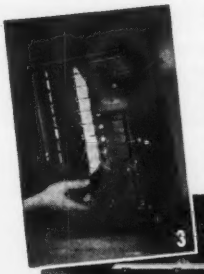

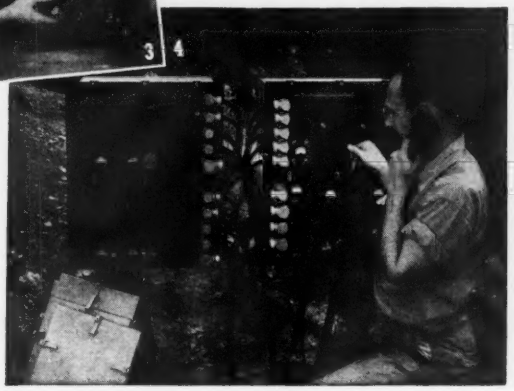

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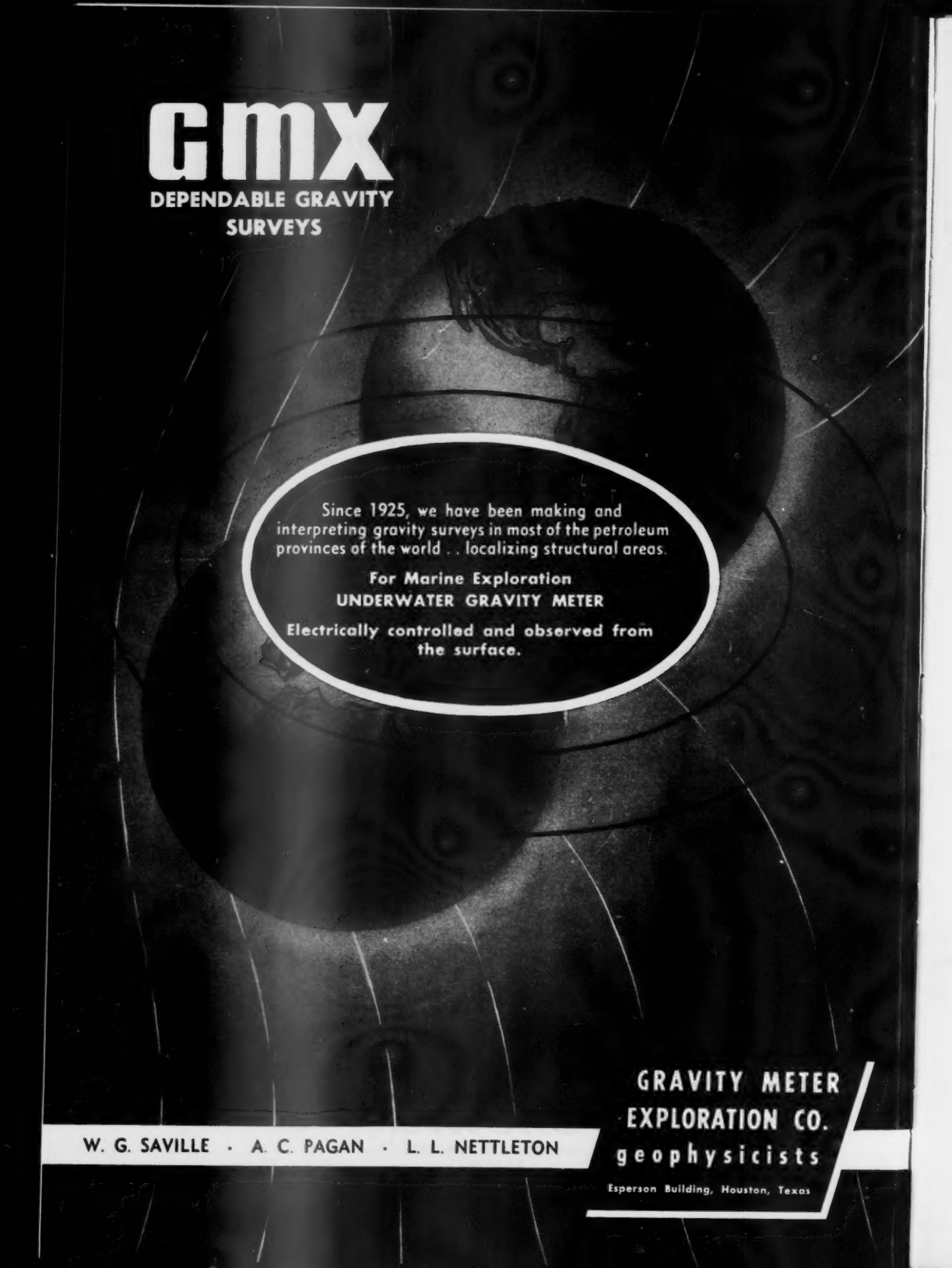
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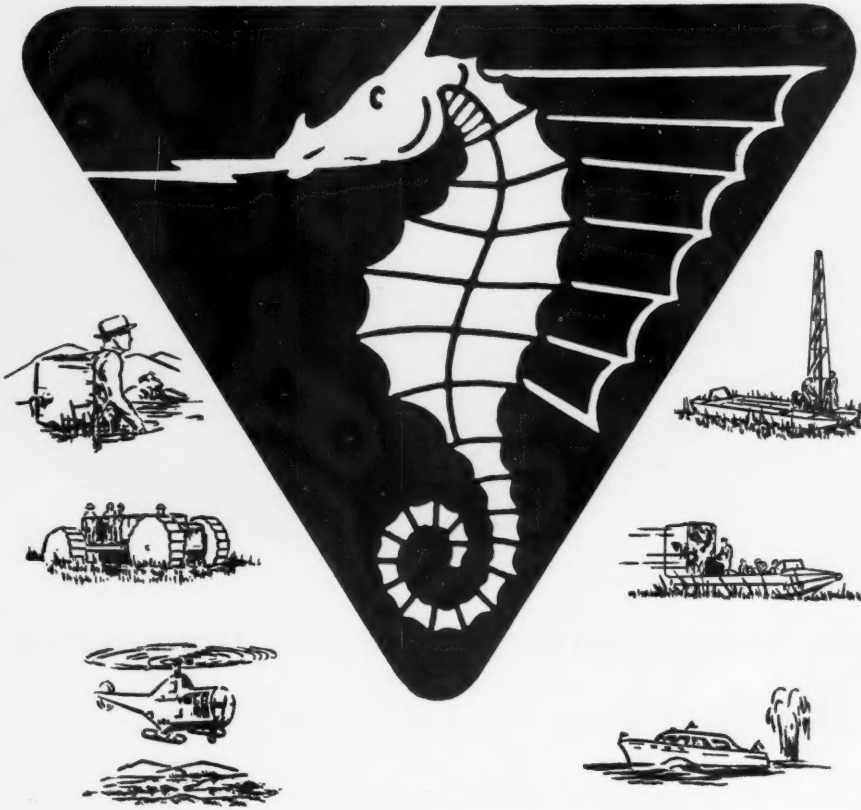

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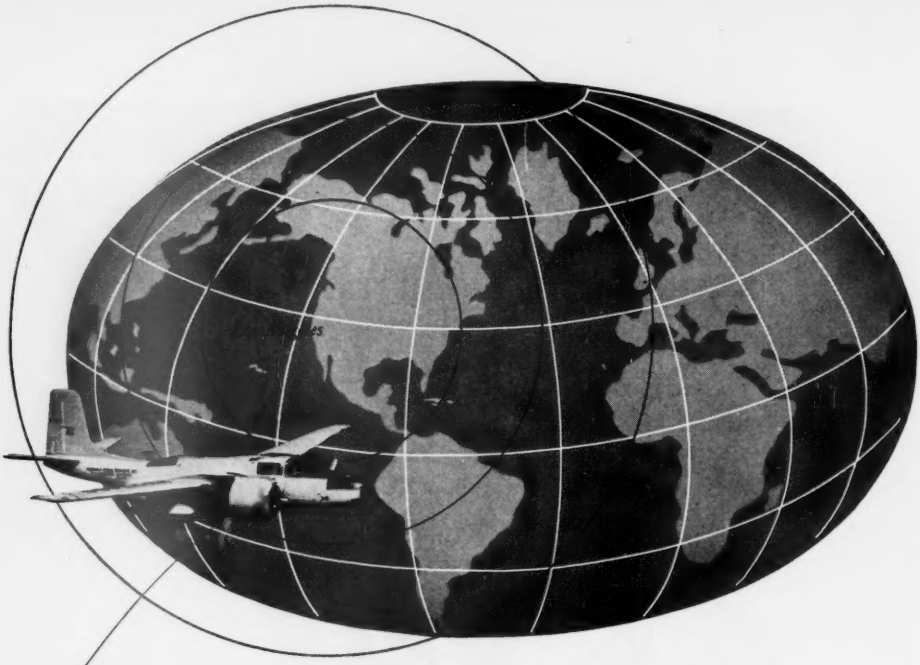

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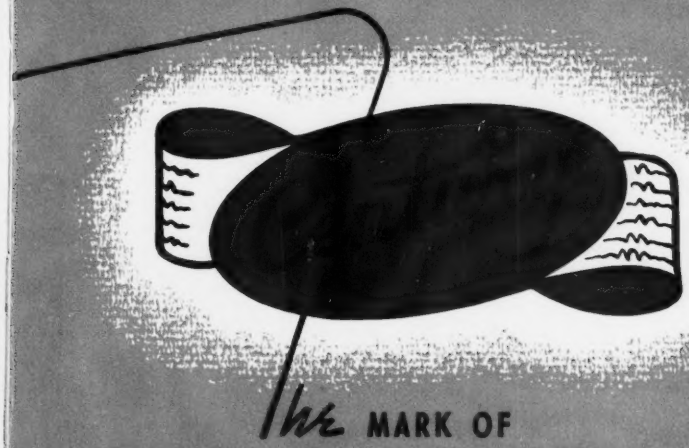

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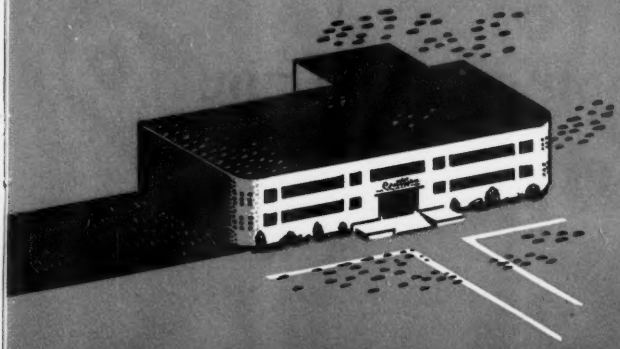

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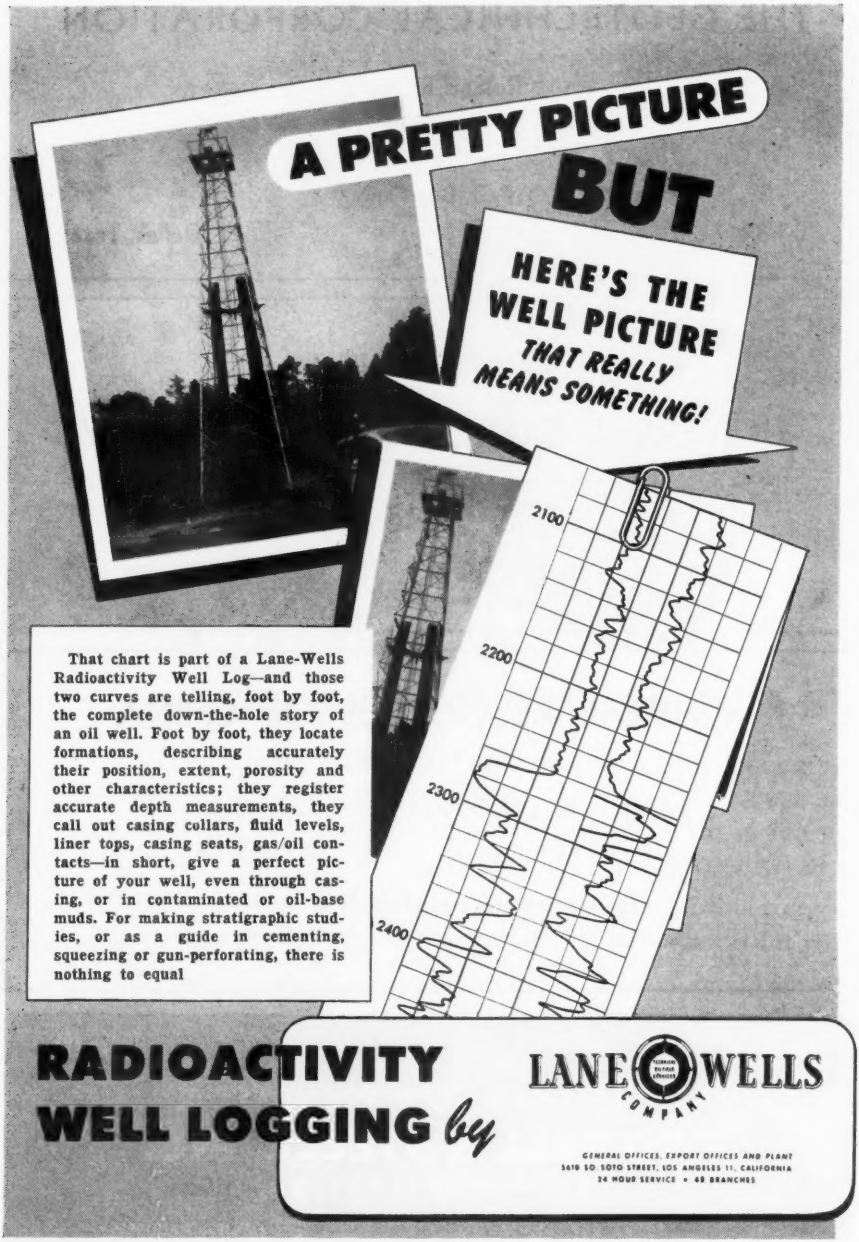
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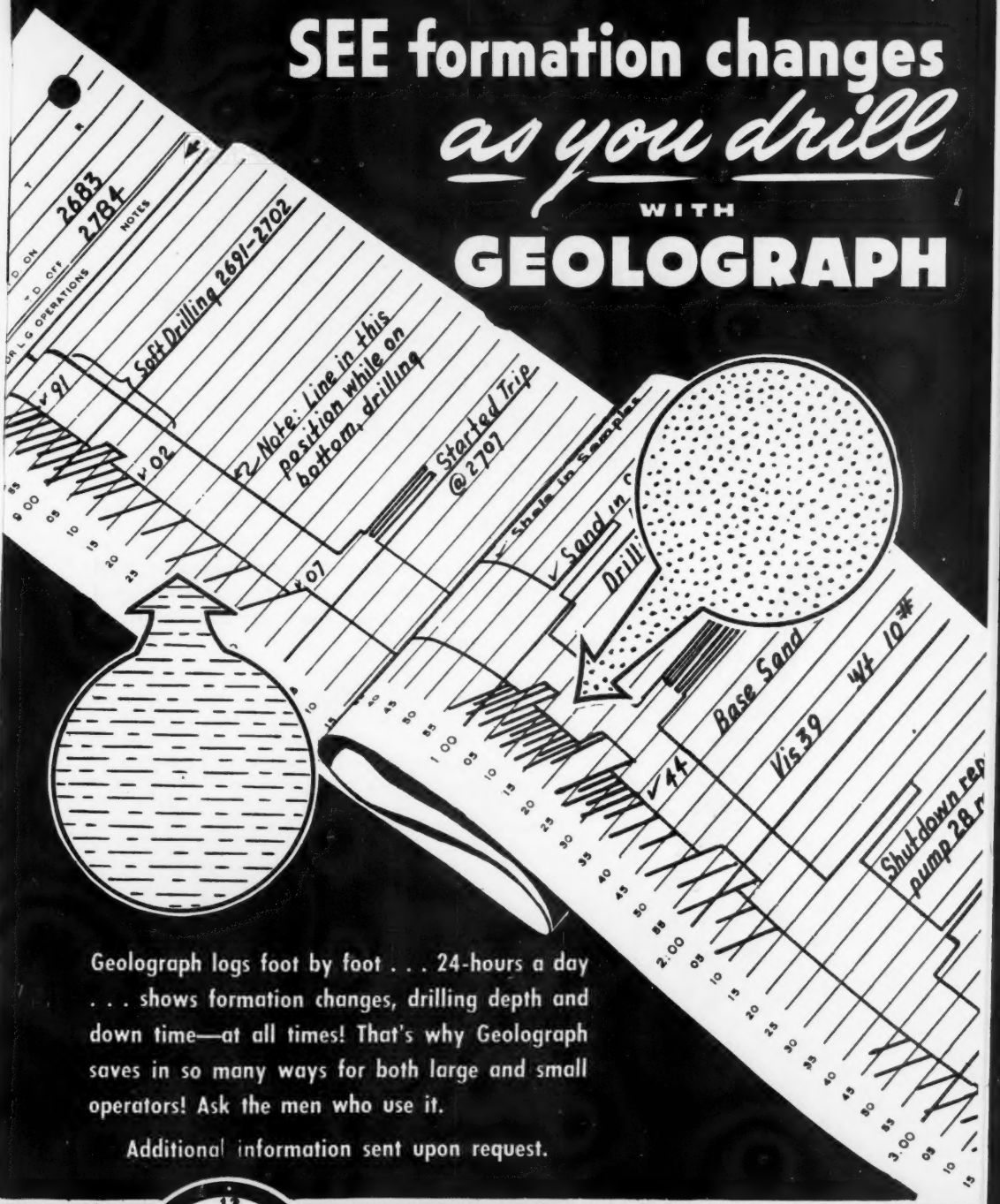

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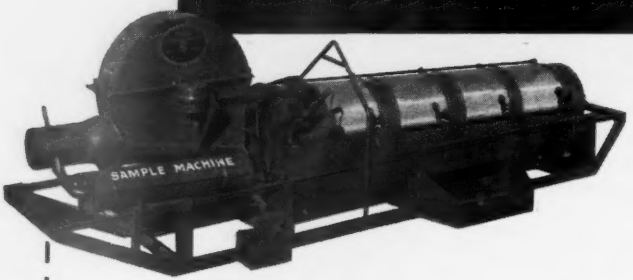

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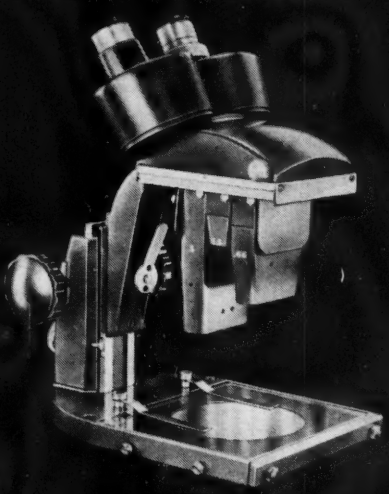

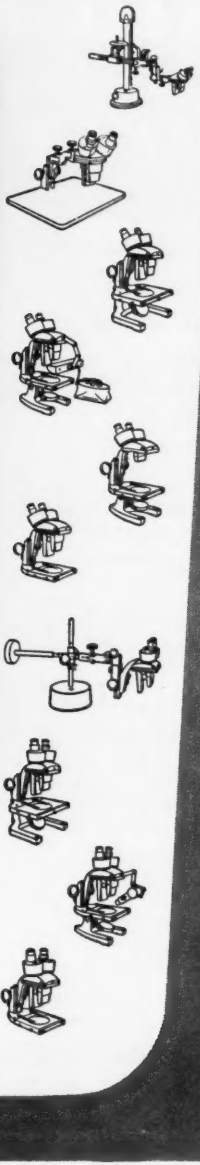

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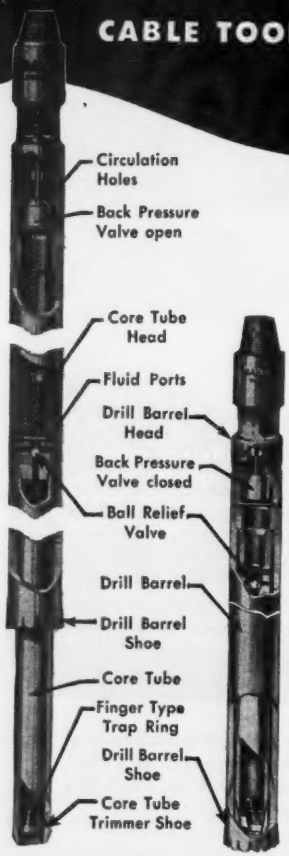

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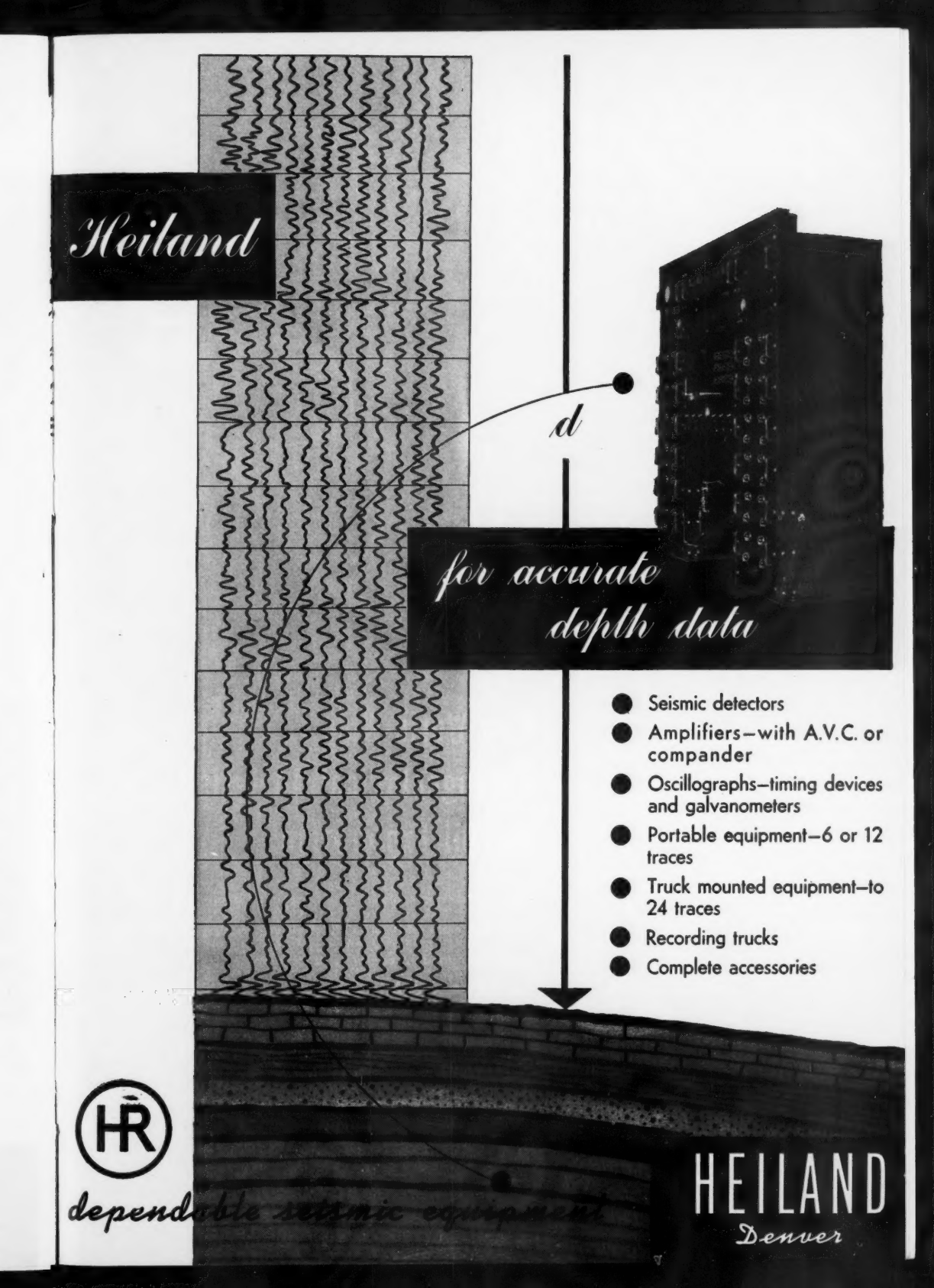
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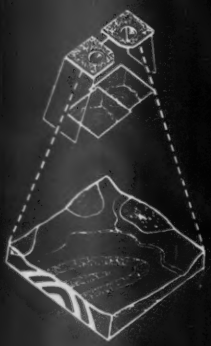

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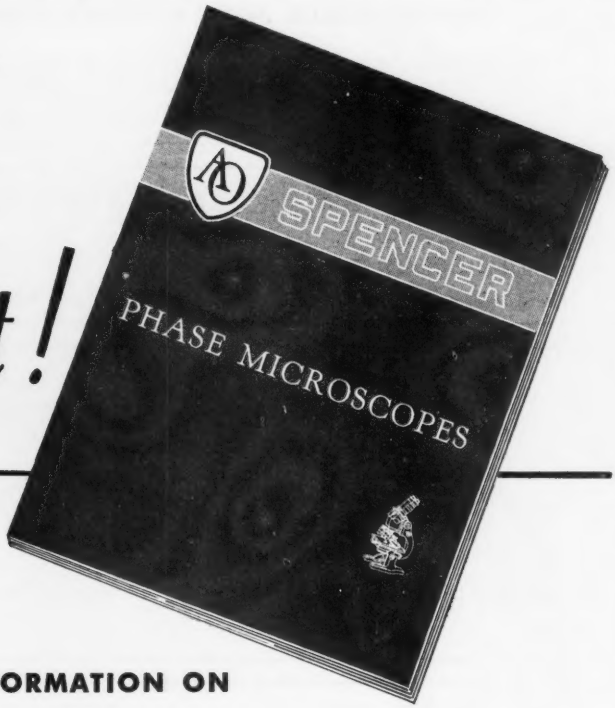

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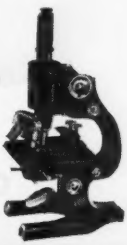

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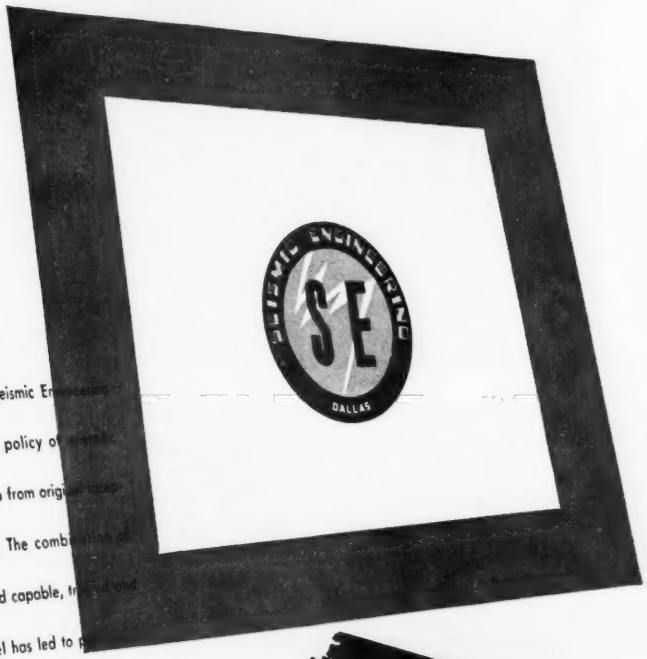

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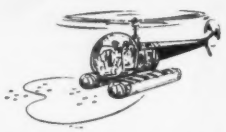

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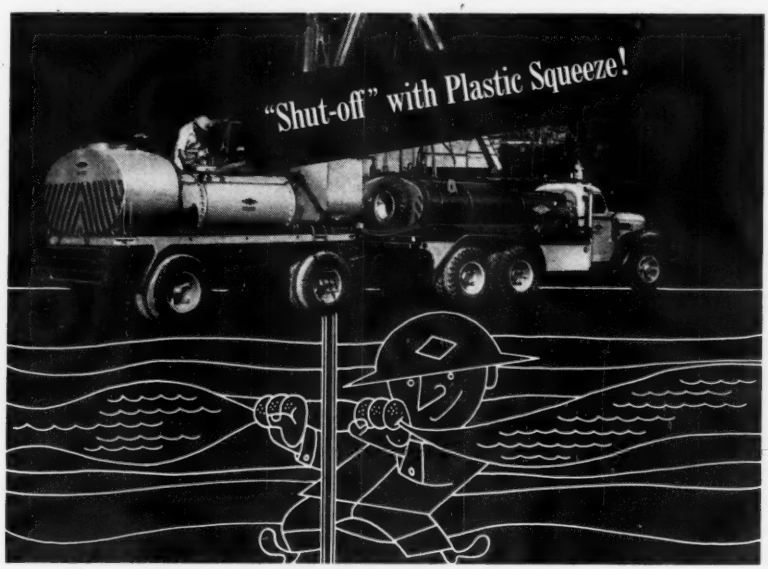

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1948 **Structure of Typical American Oil Fields.** Vol. III. McCoy Memorial Volume. 24 papers. 516 pp. 219 illus. Cloth. **To members and associates, $3.50** . 4.50

1948 **Appalachian Basin Ordovician Symposium.** From August, 1948, *Bulletin*. 264 pp. 72 illus. 6 x 9 inches. Cloth. **To members and associates, $1.50** 2.00

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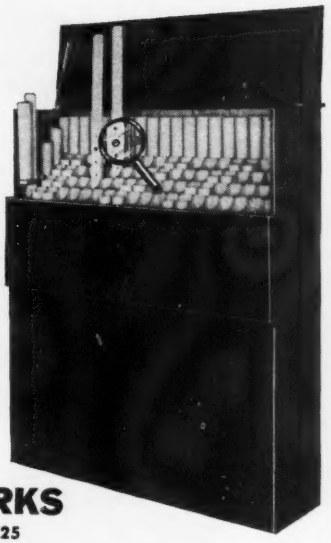

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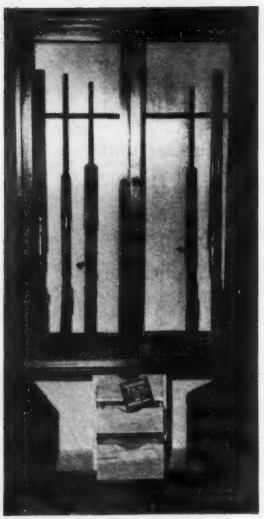

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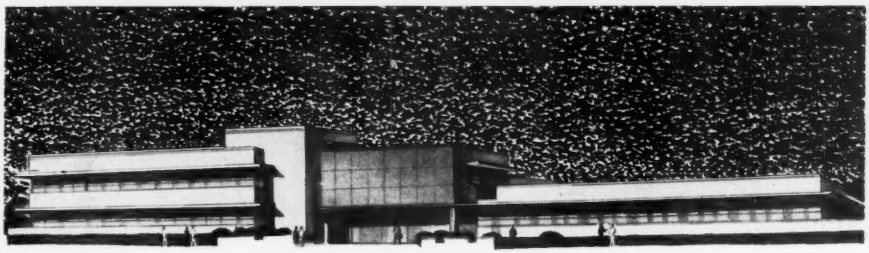

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